Draft Report

# Dredged Material Testing for Ocean Disposal

## Chevron 4H Shell Mound Project

**Prepared for**

**Science Applications International Corporation**
**10260 Campus Point Drive**
**San Diego, CA 92121**

**August 2002**

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# Chevron 4H Shell Mound Project

**Prepared for**

**Science Applications International Corporation**
**10260 Campus Point Drive**
**San Diego, CA 92121**

**Prepared by**

**AMEC Earth & Environmental, Inc.**
**5510 Morehouse Drive**
**San Diego, CA 92121**
**(858) 458-9044**

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## LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ADDAMS | Automated Dredging and Disposal Alternatives Modeling System |
| AET | apparent effects threshold |
| AMEC | AMEC Earth & Environmental, Inc. |
| ASTM | American Society for Testing and Materials |
| BCF | bioconcentration factor |
| ˚C | degrees Celsius |
| Calscience | Calscience Environmental Laboratories, Inc. |
| CCC | California Coastal Commission |
| CEQA | California Environmental Quality Act |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CSLC | California State Lands Commission |
| cy | cubic yards |
| DGPS | differential global positioning system |
| $EC_{50}$ | median effects concentration |
| EIR | Environmental Impact Report |
| EPA | U.S. Environmental Protection Agency |
| ERL | effects range-low |
| ERM | effects range-median |
| ERMq | ERM quotient |
| ET | Ecotox Threshold |
| ft | feet |
| FDA | Food and Drug Administration |
| GPC | gel permeation cleanup |
| $H_2S$ | hydrogen sulfide |
| I.D. | inner diameter |
| $LC_{50}$ | median lethal concentration |
| LCS | laboratory control spike |
| LCSD | laboratory control spike duplicate |
| LPC | limiting permissible concentration |
| mg/L | milligrams per liter |

| | |
|---|---|
| MPRSA | Marine Protection, Research, and Sanctuaries Act |
| MS | matrix spike |
| MSD | matrix spike duplicate |
| MTBE | methyl tertiary butyl ether |
| ND | nondetect |
| NOAA | National Oceanic and Atmospheric Administration |
| NOEC | no observed effects concentration |
| OSWER | Office of Solid Waste and Environmental Response |
| PAH | polycyclic aromatic hydrocarbon |
| PCB | polychlorinated biphenyl |
| RL | reporting limit |
| RPD | relative percent difference |
| SAIC | Science Applications International Corporation |
| SAP | sampling and analysis plan |
| SQB | sediment quality benchmark |
| STFATE | short-term fate |
| STLC | soluble threshold limit concentration |
| TDL | target detection limit |
| TOC | total organic carbon |
| TPH | total petroleum hydrocarbon |
| TRPH | total recoverable petroleum hydrocarbons |
| μg/kg | microgram per kilogram |
| USACE | United States Army Corps of Engineers |

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# EXECUTIVE SUMMARY

The California State Lands Commission (CSLC) is conducting an assessment of shell hash and sediment debris mounds surrounding four decommissioned oil and gas platforms off the coast of Santa Barbara, California. The remnant mounds were left following removal of the platform superstructure. The CSLC is evaluating alternatives for removing or altering the shell mounds. One of the project alternatives being considered is dredging the mounds, placing the dredged material on barges, and transporting it to the U.S. Environmental Protection Agency (EPA)-designated ocean disposal site referred to as LA-2. This open water disposal site is located approximately 5 miles south of San Pedro, California.

The U.S. Army Corps of Engineers (USACE) and EPA regulate the disposal of sediment at the ocean disposal site. These agencies have developed a tiered program for assessing the suitability of sediment for open water disposal. The tiered testing program is detailed in the guidance document titled *Evaluation of Dredged Material Proposed for Ocean Disposal* (EPA-503/8-91/001, February 1991). This document is a testing manual and is commonly referred to as the *Green Book*. The *Green Book* outlines the tiered approach for assessing sediment contamination using bioassay, bioaccumulation, and analytical chemistry tests. In addition to the *Green Book*, regional guidance has also been developed by EPA Region 9 titled *General Requirements for Sediment Testing of Dredged Material Proposed for Ocean Dumping* (December 1991). Also, a project-specific sampling and analysis plan titled *Final Sampling and Analysis Plan, Dredged Material Testing for Ocean Disposal, Chevron 4H Shell Mound Project* (AMEC 2002) was submitted for review and approval to the appropriate regulatory agencies prior to initiating field work. The *Green Book* Tier III suite of analyses conducted as part of this study includes chemical analyses for heavy metals and organics; grain size analyses; solid phase and suspended-particulate phase bioassays with sensitive test organisms; and bioaccumulation analyses with clams and worms to assess tissue residue levels.

The field collection program involved collection of sediment samples at four separate shell mound sites: Platform Hazel, Platform Heidi, Platform Hilda, and Platform Hope. Samples were collected in May 2002, using a pneumatic coring device. Four core samples were taken from each mound and separated into three vertical strata referred to as “top, middle, and bottom.” Each stratum was analyzed for chemical contamination levels. A composite sample was prepared by combining the three separate strata. The four composite samples were also analyzed for chemical contamination levels as well as toxicity and bioaccumulation potential.

The study results are summarized below.

## PLATFORM HAZEL

Chemical analyses on the sediment indicated that barium, chromium, selenium, and zinc were found in elevated concentrations above apparent effects threshold (AET)

values. Other metals were also detected at elevated levels relative to the reference sediment. The polychlorinated biphenyl (PCB) Aroclor-1254 and a variety of petroleum hydrocarbons were the organic contaminants found at elevated levels. Although there are no strict toxicity guidance values for petroleum hydrocarbons it should be noted that the petroleum hydrocarbons were the highest in the middle stratum of each platform. Polycyclic aromatic hydrocarbons (PAHs) levels were limited to pyrene and naphthalene in the top and middle strata. Naphthalene was the only PAH found over the effects range-low (ERL) value. Three volatile organics were detected at elevated levels relative to the reference sediment in the middle and bottom strata. No volatile organics were found in the top stratum. The PCB Aroclor-1254 was detected in the top and middle strata with the top stratum having the highest measurement.

Statistically significant toxicity was observed in the amphipod and mysid shrimp solid phase tests. No significant suspended-particulate phase toxicity was observed in the mysid shrimp or silverside test. The 100 percent elutriate concentration did exhibit an increase in abnormal larvae, but the $EC_{50}$ was greater than 100 percent. The clam and worm bioaccumulation tests on Hazel sediment found only barium and PAHs to have statistically significant elevated tissue concentrations compared to the reference tissue levels. Barium is not typically a contaminant of concern in dredged material assessment studies and is of minor toxicological importance. PAH bioaccumulation is a major concern in dredged material assessment studies. The total PAH levels in Hazel clam and worm tissue were 8 times and 27 times above reference tissue concentrations, respectively. Methylnaphthalenes were also detected in elevated concentrations in clam and worm tissue.

## PLATFORM HEIDI

Chemical analyses on the sediment indicated that barium, chromium, and zinc were found in elevated concentrations above their AET values. Other metals were also detected at elevated levels relative to the reference sediment. The majority of the organics were detected in the middle stratum. Petroleum hydrocarbons were measured primarily in the middle stratum. Total petroleum hydrocarbons (TPHs) were only found in this stratum and the total recoverable petroleum hydrocarbons (TRPH) were the most elevated in this stratum. Lower levels of TRPH were found in the top and bottom strata. Of the PAHs, two were detected in the middle stratum only. These were naphthalene and phenanthrene and both exceeded their ERLs. No volatile organics were detected in the top stratum but elevated levels of benzene, toluene, and xylene were measured in the middle and bottom strata. Xylene is the only volatile organic that exceeds its sediment quality benchmark (SQB).

Statistically significant toxicity was observed in the amphipod and mysid shrimp solid phase bioassay tests. No significant toxicity was observed in any of the three suspended-particulate phase exposures. Clams and worms exposed to Heidi sediment were found to have statistically elevated levels of the heavy metal barium and total PAHs. The tissue levels of total PAHs were 7 times and 24 times the reference tissue levels for clams and worms, respectively. Methylnaphthalenes were also detected in elevated concentrations in both clam and worm tissue.

## PLATFORM HILDA

Chemical analyses on the sediment indicated that barium, chromium, lead, nickel, selenium, and zinc were found in elevated concentrations exceeding their AET, ERL, or effects range-medium (ERM) values. Other metals were also detected at elevated levels relative to the reference sediment. Petroleum hydrocarbons were found primarily in the middle stratum. TPH were detected in the middle stratum, were detected at very low levels in the top stratum, and were not detected in the bottom stratum. TRPH were detected in all strata with the middle stratum containing the highest levels. PAHs were detected in only the middle stratum at levels above the ERL guidance value, but below the ERM and AET. Volatile organics were detected in all three strata; however, only acetone was detected in the bottom stratum. Again, the highest values were found in the middle stratum. Of the volatile organics found in the middle stratum 1,2,4-trimethylbenzene was the most elevated followed by p/m-xylene, naphthalene, and 1,3,5-trimethylbenzene. Aroclor-1254 was the only PCB detected and was highest in the top stratum.

Statistically significant toxicity was observed in the amphipod and mysid shrimp solid phase tests. No significant suspended-particulate phase toxicity was observed. Statistically significant bioaccumulation was measured for the heavy metal barium and total PAHs for both clams and worms exposed to Hilda sediment. Total PAH levels in test tissue was found to exceed reference tissue levels by 11 times for clams and 21 times for worms. Elevated levels of methylnaphthalenes were also detected in both clam and worm tissues.

## PLATFORM HOPE

Chemical analyses on the sediment indicated that barium, chromium, lead, nickel, selenium, and zinc were found in elevated concentrations exceeding guidance values for concentrations causing adverse biological effects. Other metals were also detected as elevated in comparison to the reference levels. The majority of the organic contaminants were detected in the middle stratum with the exception of the PCB Aroclor-1254, which was found in extremely elevated levels in the top stratum with a mean ERM quotient equal to 8.9, considered high concern. Petroleum hydrocarbons were found in all strata, but were most prevalent in the middle stratum. PAHs were detected in only the top and middle strata with three of the five PAHs detected, naphthalene, acenaphthene and phenanthrene, exceeding their ERL values. Volatile organics were measured in all strata but were found predominantly in the middle stratum. Only two volatile organics, acetone and 1,4-dichlorobenzene, were measured in the bottom stratum.

Statistically significant toxicity was observed in the amphipod bioassay test, but not the mysid shrimp solid phase test. No significant toxicity was observed in the suspended-particulate phase test. Exposure to Platform Hope sediment resulted in statistically significant bioaccumulation of barium and total PAHs in both clams and worms compared to reference tissue levels. Total PAH levels in test clams exceeded the reference clam levels by 6 times. Worm test tissue was 12 times greater in total PAH

concentrations compared to reference worm levels. Elevation levels of methylnaphthalenes were also detected in clam and worm tissue exposed to Platform Hope sediment.

## DETERMINATION

The unconfined open water disposal of dredged material is regulated under Section 103 of the Marine Protection, Research, and Sanctuaries Act (MPRSA) of 1972, Public Law 92-532. In accordance with Section 103 of the MPRSA, the USACE and EPA have established acceptability criteria for the placement of dredged material at ocean disposal sites. The disposal criteria require that the proposed dredged material meet both benthic and water column limiting permissible concentration (LPC) compliance as defined by the Ocean Dumping Law. Based on the results of this study, the Shell Mound sediment does meet the water column LPC. It does not, however, meet the benthic LPC (due to the statistically significant solid phase amphipod and mysid toxicity) and is therefore not suitable for placement at LA-2. The determination of compliance with the bioaccumulation LPC is more difficult to interpret. Barium was found to be in statistically elevated concentrations in test tissue, but barium is of little toxicological importance. PAH bioaccumulation was also significant. Total PAHs accumulated in clam tissue on average accumulated less than 10 times the reference tissue level. Worms exposed to test sediment on average accumulated total PAHs over 20 times the reference tissue levels. Worms, however, are able to readily metabolize PAHs.

# 1.0 INTRODUCTION

The California State Lands Commission (CSLC) is conducting a survey at four previously removed offshore oil and gas platforms referred to as Hilda, Hazel, Hope, and Heidi located in the Santa Barbara Channel (Figure 1). Accumulation of shell debris and other drilling-related discharges created large mounds in the vicinity of the platforms, and although these mounds provide a valuable biological habitat they are considered a hazard by commercial trawlers. Science Applications International Corporation (SAIC) has been contracted by the CSLC to prepare an Environmental Impact Report (EIR) according to the California Environmental Quality Act (CEQA). The EIR will assess the potential removal/disposal alternatives of the shell mounds. An initial sediment characterization study (de Wit 2001) of the shell mounds indicated that a more definitive study of the site was necessary. AMEC Earth & Environmental (AMEC) was contracted by SAIC to determine if the proposed dredged material is suitable for placement at a designated ocean dredged material disposal site.

The test results and disposal site recommendation presented in this report were conducted following the procedures outlined in the following documents: the project-specific *Final Sampling and Analysis Plan, Dredged Material Testing for Ocean Disposal, Chevron 4H Shell Mound Project* (AMEC 2002), *Evaluation of Dredged Material Proposed for Ocean Disposal* (*Green Book*) (EPA/USACE 1991); and *EPA Region 9 General Requirements for Sediment Testing of Dredged Material Proposed for Ocean Dumping* (EPA 1991). The aforementioned documents present a three-tiered effects-based testing strategy to determine suitability of various disposal options. For this study, Tier III (physical, chemical, and biological testing) was selected as the appropriate level of characterization, based upon the previous study by de Wit indicating sediment contamination.

The purpose of this report is to provide the CSLC, California Coastal Commission, U.S. Environmental Protection Agency (EPA), and U.S. Army Corps of Engineers (USACE) with physical, chemical, and toxicological data that will aid in determining the best method of disposal of the four mound sites.

# 2.0 BACKGROUND

The Chevron 4H site, located off the coast of Santa Barbara, California, previously had four active oil and gas drilling platforms. The platforms and the majority of the supporting structures were removed in 1996 leaving mounds of sediment and shell debris. The mounds range in height from 20 to 28 feet (6.7 to 8.5 meters) and from 185 to 230 feet in width (56.9 to 70.1 meters) situated in water depths of 95 to 150 feet (de Wit 2001). The contents of the mounds are primarily drill cuttings and shell debris that were either dropped or scraped off the supporting structures.

Prior to this study, an environmental review of the Chevron 4H Shell Mounds took place in 2001 (de Wit 2001). Physical, chemical, and biological data were analyzed and

potential methods of removal of the shell mounds and impacts were presented. The physical characteristics of the mounds were described as having "three relatively distinct strata." The first stratum, mostly shell hash, was approximately 1 to 2 feet thick and increased in thickness towards the edge and base of the mounds. The second stratum, 0.2 to 0.5 feet thick, was a composite of siltstone rock fragments, clay, fine and coarse sand, and fine-grained sediment. The final stratum was natural seafloor sediment of clay and shell fragments.

The conclusions of the de Wit study were:

1. The effects range-median (ERM) concentration for nickel was exceeded in the Strata 1 and 2 sediments at one or more sites and for polychlorinated biphenyls (PCBs) in the Stratum 1 sediment at one site.

2. The highest concentrations of all heavy metals, Total Recoverable Petroleum Hydrocarbons (TRPH), and polycyclic aromatic hydrocarbons (PAHs) in all of the strata, including the natural sediments underlying the shell mound material, exceeded the concentrations in the reference sediments.

3. Stratum 1 sediments had the highest concentrations of 12 of the 30 analytes, including eight that have established effects range-low (ERL) concentrations. Stratum 2 sediments had the highest concentration of 9 analytes, 3 of which have established ERLs. Natural sediments had the highest concentration for 6 analytes, none of which have established ERLs. Three analytes were not detected in any of the stratum sediments.

4. Highest elutriate concentrations from reference sediment were less than or equal to shell mound stratum concentrations for all analytes except arsenic, iron, mercury, titanium, phthalates, and oil and grease.

5. The results of the elutriate bioassay testing indicated that the shell mound material at Platforms Hazel, Heidi and Hilda was toxic to the test organism, mysid shrimp, Mysidopsis *bahia*. The 96-hour lethal concentration resulting in 50 percent mortality ($LC_{50}$) was 48.57 percent. The $LC_{50}$ for the other three sites exceeded 100 percent, indicating the maximum elutriate concentration was not toxic to the test organism at maximum concentration.

Based on the de Wit study, a second program was developed to more specifically address the suitability of the mound sediment for placement at LA-2. A sampling and analysis plan titled *Final Sampling and Analysis Plan, Dredged Material Testing for Ocean Disposal, Chevron 4H Shell Mound Project* (AMEC 2002) was prepared and submitted for review to the appropriate regulatory agencies.

6.

Figure 1 Regional Project Location

# 3.0 METHODS AND MATERIALS

## 3.1 MARINE SEDIMENT COLLECTION

Four sampling locations were selected within each of the four shell mound sites (Appendix A). All sediment samples were collected using a pneumatic vibracore between 14 May and 17 May 2002. The collection device has an 800 pound vibracore head that consists of a vertical 8-inch piston driver. Photographs of the collection device and operation, and sediment core samples are contained in Appendix B. The action of the piston creates a sharp percussive hammer drive that advances the core barrel, which is attached to the bottom of the drive head, into the seafloor sediments.

The vibracore system was deployed from the *Danny C* in a "stand alone" mode on the seafloor by means of a support frame. The frame maintains the vertical orientation of the vibracore system and, most importantly, de-couples it from the motion of the vessel. The vibracore uses a 4-inch-diameter aluminum (alloy 66030) tube connected to a stainless steel nosepiece. The core barrel utilized was 4-inch inner diameter (I.D.), 0.25-inch-diameter wall black pipe. The barrel was lined with a 3.5-inch I.D. clear butyl acetate tube that isolates the sample from contamination from the barrel. The vibrating unit is encased in aluminum and uses electricity (240-volt, 3-phase, 26-amp) to drive two outer-rotating vibrators. The vibracore head and tube were lowered by a hydraulic winch and vibrated until penetration was stopped by sediment resistance (e.g., hard clay) or at project depth. The vibracore was then turned off and the tube extracted from the sediment and returned to the vessel. The sediment was then extruded onto a Teflon-lined tray. TEG Ocean Services provided the vibracore equipment and personnel used to sample the sediments while Castegnola Tug Service and Fugro West, Inc. supported the collection effort by providing vessel and logistical support.

The vessel was positioned over the shell mounds utilizing Differential Global Positioning System (DGPS), which provides latitude and longitude information (NAD83 data) prior to sampling. The accuracy of the DGPS data used for this sampling event was approximately 3 meters. Once confirmation was made, the anchor tender vessel deployed a three-point anchor spread that held the coring vessel over the mound. Coring locations and vertical dimensions were verified using current bathymetry and real-time tide and depth information.

Each core was photographed and the unique strata were identified and noted. Sediment collection, handling, and preservation activities followed the procedures outlined in the SAP (AMEC 2002), the *Green Book*, and in regional guidance documents. The EPA and USACE reviewed the SAP and both concurred with the proposed approach. Descriptions of sediment samples, field conditions, and meteorological events were recorded in the field log as described in the SAP. The following information was recorded during the test sediment collection program:

- date and time of collection

- sample identification code
- sampling location (to within a 3-meter accuracy)
- water depth
- tide stage and currents
- climatic conditions
- sampling method
- sampler penetration (sample length)
- description of the material type of the samples
- description of any vertical stratification in each core
- number of individual sediment samples comprising each composite
- photographic documentation of a representative core collected at each location

Reference sediment was collected 17 May 2002 from the LA-2 reference site using a stainless steel pipe dredge (Figure 2). The sediment was held in sealed plastic bags, placed on ice in coolers, and transported immediately to a 4 degrees Celsius (°C) refrigeration unit.

## 3.2 SEDIMENT ANALYSES

Each core was homogenized and sampled for chemical testing. All sediment from the same strata within the same shell mound site was then composited, subsampled for archival purposes, and the labeled jars were stored at 4 °C. It should be noted that the bottom strata of most cores were the most difficult to composite because they primarily consisted of hard clay sediment. The sediments from all four cores were then composited and sent in coolers with ice with the individual stratum samples to Calscience Environmental Laboratories (Calscience) for chemical analysis. A set of only the composited samples was kept and stored at 4°C for in-house bioassay and bioaccumulation testing. The sediment samples submitted to Calscience were analyzed for the chemicals listed in Table 1.

Soluble threshold limit concentration (STLC) leaching procedure tests were also performed on several metals. The STLC analyses were conducted to determine if the sediment could be classified as a hazardous or nonhazardous waste according to California Title 22 criteria. The purpose of this testing is to assess whether upland disposal is necessary. STLC tests are not typically a component of a *Green Book* study. STLC analyses were conducted on the metals that had sediment concentrations (barium, chromium, and lead) that were 10 times or more above the given STLC value for the particular analyte.

## 3.3 BIOASSAY TESTING

Bioassays were conducted on composite sediment samples from all four sites. The test series included bioassays conducted on three sediment phases: (1) solid phase, (2) suspended-particulate phase, and (3) bioaccumulation phase. Each of these tests was performed in accordance with the *Green Book* and EPA's *General Requirements for Sediment Testing of Dredged Material Proposed for Ocean Dumping* (EPA 1991).

Seawater used in tests was collected at Scripps Institution of Oceanography and transported to AMEC's Bioassay Laboratory in San Diego, California. This water was used in lieu of seawater collected at the disposal site based upon past analyses of the physical and chemical characteristics of each water type that showed both to be similar in composition and quality.

### 3.3.1 Test Organisms

Table 2 provides a list of the organisms tested in the three-phase bioassay series. Test organisms underwent a holding period under laboratory and test conditions prior to test initiation. The holding period included an initial 48-hour acclimation period, which served to evaluate the health and acceptability of field-collected test specimens. During the acclimation period, test animals were slowly exposed to laboratory water, test temperature, and other test and laboratory conditions. If the animals were deemed acceptable after the acclimation period, they underwent a holding period during which the animal's health was closely monitored. An evaluation of test organism acceptability during the acclimation and holding periods was used to determine if testing should proceed or should be delayed until a new batch of test organisms could be obtained. Test organism health and acceptability were determined to be within normal limits and testing proceeded as planned.

### 3.3.2 Solid Phase Toxicity Tests

Ten-day amphipod and mysid shrimp tests were conducted under static renewal conditions in 1-liter glass beakers according to the protocol described in American Society for Testing and Materials (ASTM) (1990). Tests were prepared with the additionof a 2-centimeter layer of control, reference, or test sediment and 950 milliliters of clean seawater into each test beaker. Gentle aeration was added to each chamber through a 1-milliliter, cotton-plugged pipette.

Twenty amphipods were distributed randomly to each beaker, with 5 replicates exposed to each sediment treatment. After 10 days, test animals were removed by gently sieving the contents of each beaker through a nitex mesh screen. Animals were collected on the screen and final counts were made. The initial anphipod test was repeated because the controls did not meet the 90 percent survival standard set by the *Green Book*.

Modifications to the setup procedure were made during the second amphipod test to mitigate against the potential effects of elevated levels of ammonia and sulfides in the

sediment porewater. Ammonia levels were monitored and water changes were performed before the animals were added and two times thereafter for the duration of the test. Porewater sulfides were also measured in each sample and four surrogate replicates were utilized during the test. The surrogates were tested for ammonia before the first water change, after the second and third water changes before the animals were added, and at the end of the test.

The mysid test was conducted with 10 individuals distributed randomly per replicate container. After 10 days, test animals were removed by gently sieving the contents of each beaker through a nitex mesh screen. Animals were collected on the screen and final counts were made.

### 3.3.3 Suspended-particulate Phase Toxicity Tests

The test solution used in the suspended-particulate phase bioassays was prepared by mixing seawater and test sediment to yield a volumetric sediment:water ratio of 1:4. Aeration and mechanical mixing, using a stainless steel impeller, was applied to vigorously agitate the mixture for 30 minutes. After a 1-hour settling period, the supernatant was drained from the top of the mixing chamber. This material was considered to be 100 percent elutriate and was used to mix the concentrations used for all suspended-particulate phase testing.

The 100 percent elutriate was diluted with clean seawater to prepare the four test concentrations, which were 0 percent (control, no supernatant), 10, 50, and 100 percent supernatant solutions. The test material was distributed to individual test chambers, and initial water quality readings were taken. Readings included dissolved oxygen, pH, temperature, ammonia, and salinity. If dissolved oxygen was found to be below 60 percent of saturation, all test chambers were aerated. Testing was initiated by randomly adding test organisms to individual test chambers. Water quality was monitored daily thereafter to ensure proper and constant test conditions and was found to be acceptable.

### 3.3.4 Bioaccumulation Phase

Bioaccumulation testing was performed using the polychaete worm (*Nereis virens*) and the bent-nose clam (*Macoma nasuta*) over a 28-day test period under flow-through conditions. Testing was initiated using reference and test sediments in the same manner as described for the 10-day solid phase tests. For this test, however, 10-gallon glass aquariums were stocked with 10 polychaete worms and 35 clams per replicate. This number of organisms is necessary to generate the amount of biomass necessary to conduct all the required chemical analyses. The chambers were maintained under flow-through conditions and daily water quality measurements were taken on each chamber as specified in the 28-day test.

Upon test termination, the reference and test sediments were sieved to remove the worms and clams. Surviving animals were placed, by replicate, in clean sand in an aquarium and held under flow-through conditions to depurate for 24 hours. Sediments

Figure 2 LA-2 Disposal and Reference Sediment Collection Sites

**Table 1. Methods for Sample Preparation, Cleanup, and Analysis, and Detection Limits for Sediments and Tissues**

| Analyte | Preparation Method | Cleanup Methods[a] | Analysis Method | Sediment Target Detection Limit[b] | Tissue Target Detection Limit[b] |
|---|---|---|---|---|---|
| Total Solids (%) | – | – | 160.3 | 0.1 | – |
| Total Organic Carbon (%) | Acidify to release carbonates | – | 9060 | 0.01 | – |
| Total Ammonia (mg/kg) | – | – | 350.2M[c] | 0.2 | – |
| Total & Soluble Sulfides (mg/kg) | Zinc acetate preserve | – | 376.2M[c] | 0.1 | – |
| Grain Size (%) | – | – | ASTM D422-63[d]; Plumb[e] | 0.1 | – |
| Antimony (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | – |
| Arsenic (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | 0.25 |
| Barium (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | 0.1 |
| Beryllium (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | 0.1 |
| Cadmium (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | 0.1 |
| Chromium (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | 0.02 |
| Cobalt (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | – |
| Copper (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | 0.1 |
| Lead (mg/kg) | 3051[f] | – | 6020[f] | 5.0 | 1.0 |
| Mercury (mg/kg) | Total Digestion | – | 7471A[f] | 0.02 | 0.02 |
| Molybdenum (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | – |
| Nickel (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | 1.0 |
| Selenium (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | 0.5 |
| Silver (mg/kg) | 3051[f] | – | 6020[f] | 0.2 | 1.0 |
| Thallium (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | 0.1 |
| Vanadium (mg/kg) | 3051[f] | – | 6020[f] | 0.1 | 0.1 |
| Zinc (mg/kg) | 3051[f] | – | 6020[f] | 2.0 | 1.0 |
| STLC metals (mg/L) | | | 6010B | | |

**Table 1 (continued)**

**Methods for Sample Preparation, Cleanup, Analysis, and Detection Limits for Sediments and Tissues**

| Analyte | Preparation Method | Cleanup Methods[a] | Analysis Method | Sediment Target Detection Limit[b] | Tissue Target Detection Limit[b] |
|---|---|---|---|---|---|
| TRPH (mg/kg) | – | – | 418.1M[f] | 5.0 | |
| PAHs[g] (µg/kg) | 3550A[f] | 3640A[f]/3660B[f] | 8270C[f] | 20 | 20 |
| Organochlorine Pesticides[h] (µg/kg) | 3550A[f] | 3620B[f]/ 3640A[f]/ 3660B[f] | 8081A/8082[f] | 0.5 - 30 | 0.5 - 25 |
| PCBs[i] (µg/kg) | 3550A[f] | 3620B[f]/ 3640A[f]/ 3660B[f]/ 3665A[f] | 8082[f] | 20 | 20 |
| Phenols (mg/kg) | 3545[f] | – | 8270C | 20 - 100 | – |
| Phthalates (mg/kg) | 3545[f] | – | 8270C | 10 | – |
| Organotins (µg/kg) | Rice et al.[j] | – | Rice et al.[j] | 1 | – |
| Volatile Organic Compounds (µg/kg) | | | 8260B | 10 | |

mg/kg – milligrams per kilogram
µg/kg – micrograms per kilogram
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
STLC – soluble threshold limit concentration
TRPH – total recoverable petroleum hydrocarbons

[a] Alternative cleanup procedures are described in U.S. EPA SW846 (1986). Additional cleanup procedures may be necessary on a sample-by-sample basis.

[b] Sediment minimum levels are on a dry-weight basis. Tissue minimum levels are on a wet-weight basis. To achieve the recommended minimum levels for some compounds in sediment, it may be necessary to use a larger sample size than the method describes, a smaller extract volume for gas chromatography/mass spectrometry analyses, and one of the recommended sample cleanup methods, as necessary, to reduce interference.

[c] Standard Methods for the Examination of Water and Wastewater, 19th Edition 1995.

[d] ASTM D1234.

[e] Procedures for Handling and Chemical Analysis of Sediment and Water Samples, Russell H. Plumb, Jr., EPA/CE-81-1, May 1981, Particle Size, Method 2, apparent particle-size distribution.

[f] SW-846, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Revision 3 (Nov. 1986), as amended by Updates I (Jul 1992), II (Sep 1994), IIA (Aug 1993), IIB (Jan 95), and III (Dec 96).

[g] Includes 14 PAH compounds (LPAHs: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene; HPAHs: fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b&k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, benzo(g,h,i)perylene.

[h] Includes Aldrin, a-BHC, b-BHC, g-BHC (Lindane), d-BHC, Chlordane, 4,4-DDD, 4,4-DDE, 4,4-DDT, Dieldrin, Endosulfan I and II, Endosulfan sulfate, Endrin, Endrin aldehyde, Heptachlor, Heptachlor epoxide, and Toxaphene.

[i] Includes Aroclors 1016, 1221, 1232, 1242, 1248, 1254, 1260, and 1262.

[j] Rice, C.D., F.A. Espourteille, and R.J. Huggett. 1987. Analysis of tributyltin in estuarine sediments and oyster tissue, *Crassostrea virginica*. Applied Organometallic Chemistry, 1:541-544.

**Table 2**

**Test Species**

| Test Organism | Taxon | SPP | SP | BP |
|---|---|---|---|---|
| Bivalve Larvae | *Mytilus edulis* | X | | |
| Silverside | *Menidia beryllina* | X | | |
| Mysid shrimp | *Americamysis bahia** | X | X | |
| Amphipod | *Ampelisca abdita* | | X | |
| Polychaete | *Nereis virens* | | | X |
| Mollusk | *Macoma nasuta* | | | X |

SPP – suspended-particulate phase
SP – solid phase
BP – bioaccumulation phase
*formerly *Mysidopsis bahia*

eliminated by the animals during depuration were removed periodically. Following depuration, animals were carefully removed from the holding chambers, placed into labeled, zipper-sealed plastic storage bags, and frozen. Each bag was assigned a random number. Frozen test tissue was transported to Calscience and CGR Marine Laboratory in Torrance, California, for chemical analyses.

A suite of chemical analyses similar to that used to test sediments was applied to the bioaccumulation tissue samples. The constituents analyzed, along with their respective target detection limits, are included in Table 1.

## 3.4 STATISTICAL ANALYSES

Statistical analyses were used to evaluate all bioassays following the guidelines in the *Green Book*. In cases where average survival in the test medium equals or exceeds that of the reference, no statistical analysis was performed. Dunnett's test using the statistical software TOXCALC was conducted on suspended-particulate phase results to assess significant reductions in fish and mysid shrimp survival or normality in bivalve larvae test. A one-tailed *t*-test using the Microsoft Excel data management tool was used for solid phase test results comparing the test site sediment survival to the reference site.

Statistical analysis of the bioaccumulation test data compared tissue concentrations from animals held in reference sediment to concentrations from tissues exposed to test sediments. Significance was determined using a one-tailed *t*-test using the Microsoft Excel data management tool. For analytes measured at or below the detection limit, the statistical test was carried out using the detection limit as the concentration. In cases where reference concentrations exceeded treatment concentrations, no statistical analyses were performed.

# 4.0 RESULTS

This section describes the results (physical, chemical, and biological) of the *Green Book* Tier III study conducted on sediment collected at the Shell Mound project site.

## 4.1 FIELD OBSERVATIONS

Sampling locations are contained in Appendix A and in Table 3.

Field logs were maintained daily and are summarized in Table 3; original field logs are included in Appendix C. Photographic documentation of the cores is presented in Appendix B.

**Table 3**

**Summary of Field Log Data**

| Site | Coring Location | Position (Latitude, Longitude) | Target Penetration (ft) | Core Recovery (ft) | Comments |
|---|---|---|---|---|---|
| Hazel | 1 | 34° 22.9914'<br>119° 34.0845' | 30 | 15 | Top 7 ft no shell hash, mid strata some shell debris and cuttings mid strata, hard gray clay and petroleum odor bottom 7 ft |
| | 2 | 34° 22.9947'<br>119° 34.0817' | 30 | 22 | Top strata no shell hash, distinct cuttings with some dark clay, no native material |
| | 3 | 34° 22.9951'<br>119° 34.0749' | 30 | 18 | Top 4 ft shell hash, black silt and $H_2S$ odor; 12 ft cuttings and mud, petroleum odor |
| | 4 | 34° 22.9975'<br>119° 34.0704' | 30 | 22 | Top 6 ft shell hash, oil sheen and black; middle 11 ft cuttings and mud, some oil; bottom 5 ft clay |
| Hilda | 1 | 34° 23.3159'<br>119° 35.7654' | 30 | 24 | Top 0.5 ft shell hash; middle 21 ft drill cutting and mud, upper stratum have fairly coarse gravel and becomes finer as you move down the core, old oil residue; bottom 2.5 ft native sediment |
| | 2 | 34° 23.3198'<br>119° 35.7596' | 30 | 24 | Top 4 ft shell hash, odor from water decanting from top of core, oil sheen; middle 8 ft drill cuttings and mud; bottom 12 ft native sediment |

**Table 3 (continued)**
**Summary of Field Log Data**

| Site | Coring Location | Position (Latitude, Longitude) | Target Penetration (ft) | Core Recovery (ft) | Comments |
|---|---|---|---|---|---|
| Hilda | 3 | 34° 23.3222' 119° 35.7566' | 30 | 20 | Top 1 ft shell hash, oil sheen, strong odor; middle 9 ft drill cuttings and mud, large amount of shell debris and oil mixed in with cuttings; bottom 10 ft native bottom |
| | 4 | 34° 23.3264' 119° 35.7529' | 30 | 21 | Top 5 ft shell hash; middle 1 ft cuttings and mud; bottom 15 ft native bottom |
| Heidi | 1 | 34° 20.5456' 119° 31.1829' | 30 | 16 | Top 6 ft shell hash, $H_2S$ odor; middle 5 ft cuttings and mud, slight sheen; bottom 5 ft native clay |
| | 2 | 34° 20.5458' 119° 31.1842' | 30 | 19 | Top 5 ft shell hash, black, $H_2S$ odor, oil drops; middle 9 ft cuttings and mud, some loose sand, brown with petroleum odor; bottom 5 ft native sticky clay |
| | 3 | 34° 20.5488' 119° 31.1784' | 30 | 20 | Top 5 ft black with shell hash; middle 7 ft cuttings with mud and sand, light petroleum odor; bottom 10 ft native clay |
| | 4 | 34° 20.5501' 119° 31.1724' | 30 | 17 | Top 2 ft shell hash with petroleum odor; middle 2 ft cuttings with mud and petroleum odor; bottom 13 ft native clay |
| Hope | 1 | 34° 20.4448' 119° 31.9110' | 30 | 4 | Top 3.5 ft shell hash; bottom drill cuttings and mud; refusal – very hard concrete; no bottom strata |
| | 2 | 34° 20.4476' 119° 31.9062' | 30 | 27 | Top 6.5 ft shell hash; middle 12.5 ft cuttings and mud, oil smell; bottom 8 ft native sediment with 2 ft layer of sand between middle and bottom strata and sandy plug |
| | 3 | 34° 20.4492' 119° 31.9017' | 30 | 21.5 | Top 3 ft shell hash with 1 ft silty mud; middle 5 ft cuttings and mud; bottom 13.5 ft native clay |
| | 4 | 34° 20.4545' 119° 31.9095' | 30 | 6.5 | All was sandy shell hash, core traveled along tangent on the mound rather than perpendicular |

ft - feet

$H_2S$ - hydrogen sulfide

## 4.2 SEDIMENT TEST RESULTS

### 4.2.1 Physical Results

Sediment grain size, total organic carbon (TOC), and solids results are summarized in Table 4. The grain size distribution for the Chevron 4H Shell Mounds sediments was dominated by the silt and sand fractions. All of the material that made up the gravel fraction was shell hash. Original grain size data can be found in Appendix D.

### 4.2.2 Chemistry Results

The results of the bulk sediment chemical analyses are presented in this section. Original chemistry reports are included in Appendix E. The chemical levels obtained in this study are compared to several established sediment quality guideline levels. The guidelines used for comparison are referred to as the effects range-low (ERL), effects range-median (ERM), and apparent effects threshold (AET). ERLs and ERMs were developed by analyzing effects versus chemistry results for numerous studies. The ERL is calculated as the lower $10^{th}$ percentile concentration of the available sediment toxicity data that has been screened only for those samples identified as toxic by the original studies investigators (Buchman 1999). The ERM is the median concentration of the compiled data.

AET concentrations were developed specifically for Puget Sound. The concentrations were determined by conducting a series of biological tests (bioassay, benthic infaunal analyses) and chemical analyses on multiple sediment samples with a wide range of chemical levels. The AET concentration represents the level above which adverse effects would always be expected if organisms were exposed to that specific contaminant.

The sediment guidelines presented in this report are for comparison sake only. They do not represent federal sediment quality criteria or cleanup levels, nor do they allow for the determination of ocean disposal acceptability.

*Metal and General Chemistry*

Sulfides, ammonia, and metals results (dry weight) are presented in Table 5. The metals beryllium, silver, and thallium were not detected in any of the shell mounds. Arsenic, barium, chromium, cobalt, copper, lead, nickel, vanadium, and zinc were detected at all shell mounds. Low levels of certain analytes were detected in the reference sediment. These include arsenic, barium, chromium, cobalt, copper, lead, nickel, vanadium, zinc, and mercury. Of these analytes, only barium exceeded the AET value and none of the analytes exceeded the ERL or ERM values.

## Table 4

## Bulk Sediment Physical Results

| Analyte | Units | Hazel | | | | Heidi | | | | LA-2 Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Top | Middle | Bottom | Comp. | Top | Middle | Bottom | Comp. | |
| Classification | | SANDY* SILT | SANDY SILT | SILT w/sand | sandy SILT | SILTY SAND | SILTY SAND | SILT | SILTY SAND | SANDY SILT |
| Gravel | % | 24.5 | 8.3 | 0.3 | 16 | 38.9 | 3 | 0.2 | 23.3 | 0 |
| Sand | % | 20 | 27.2 | 14.7 | 26.5 | 30.6 | 51 | 1.8 | 29.7 | 58 |
| Silt | % | 40 | 54 | 70.5 | 50.5 | 22.5 | 40.5 | 70.5 | 39.5 | 36 |
| Clay | % | 15.5 | 10.5 | 14.5 | 7 | 8 | 5.5 | 27.5 | 7.5 | 6 |
| Solids | % | 48.7 | 60.3 | 72.7 | 60.9 | 61.5 | 62.1 | 63 | 60 | 66.3 |
| TOC | mg/kg | 0.65 | 0.98 | 0.41 | 0.67 | 0.18 | 0.56 | 0.52 | 0.5 | 0.4 |
| Analyte | Units | Hilda | | | | Hope | | | | LA-2 Reference |
| | | Top | Middle | Bottom | Comp. | Top | Middle | Bottom | Comp. | |
| Classification* | | SILTY SAND | SANDY SILT | SILT | SANDY SILT | silty SAND | SILTY SAND | SILT | silty SAND | SANDY SILT |
| Gravel | % | 41 | 8.9 | 0.5 | 19.8 | 29.7 | 6.5 | 0.4 | 28.5 | 0 |
| Sand | % | 21 | 28.1 | 4.5 | 10.7 | 49.8 | 62.5 | 4.4 | 41.5 | 58 |
| Silt | % | 29 | 49 | 76 | 55.5 | 18 | 23 | 66.7 | 25 | 36 |
| Clay | % | 9 | 14 | 19 | 14 | 2.5 | 8 | 28.5 | 5 | 6 |
| Solids | % | 60 | 57.5 | 67.6 | 61.4 | 62.8 | 63.5 | 61.2 | 66.1 | 66.3 |
| TOC | mg/kg | 0.72 | 1.2 | 0.7 | 0.82 | 0.43 | 0.29 | 0.52 | 0.45 | 0.4 |

TOC – total organic carbon
mg/kg – milligrams per kilogram
Comp. – composite
% – percent
* capitalized indicates the majority of the sediment is this size fraction

## Table 5. Metals and General Chemistry Results

| Analyte | Units (dry wt.) | Hazel | | | | Heidi | | | | LA-2 Reference | ERL | ERM | AET | 10X STLC | TTLC (wet wt.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Top | Middle | Bottom | Comp. | Top | Middle | Bottom | Comp. | | | | | | |
| Antimony | mg/kg | 2.12 | ND | ND | ND | ND | ND | ND | ND | ND | | | 9.3 | 150 | 500 |
| Arsenic | mg/kg | 4.81 | *9.34* | 5.87 | 7.32 | 3.06 | 3.14 | 5.38 | 2.93 | 1.88 | 8.2 | 70 | 57 | 50 | 500 |
| Barium | mg/kg | 4030 | 3670 | 1620 | 4220 | 4790 | 5530 | 348 | 3870 | 76.0 | | | 48 | 1000 | 10000 |
| Barium (STLC) | mg/L | 3.52 | 23 | 5.03 | 19.2 | 4.63 | 16.2 | * | 11.2 | * | | | | | |
| Beryllium | mg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND | | | | 7.5 | 75 |
| Cadmium | mg/kg | ND | *1.87* | ND | *2.39* | ND | ND | ND | ND | ND | 1.2 | 9.6 | 2.7 | 10 | 100 |
| Chromium (Total) | mg/kg | 67.0 | *101* | 43.8 | *82.6* | 46.8 | *119* | 36.1 | 67.6 | 15.6 | 81 | 370 | 96 | 50 | 2500 |
| Chromium (STLC) | mg/L | 0.84 | 2.77 | * | 1.93 | * | 5.11 | * | 3.3 | * | | | | | |
| Cobalt | mg/kg | 5.48 | 4.83 | 6.79 | 4.80 | 4.06 | 3.02 | 7.91 | 3.31 | 3.17 | | | | 800 | 8000 |
| Copper | mg/kg | 19.8 | 33.5 | 8.84 | 33.2 | 26.2 | 11.9 | 12.0 | 10.4 | 3.90 | 34 | 270 | 390 | 250 | 2500 |
| Lead | mg/kg | 30.0 | *110* | 14.8 | *95.2* | 16.5 | 16.3 | 11.4 | 12.6 | 4.26 | 46.7 | 218 | 430 | 50 | 1000 |
| Lead (STLC) | mg/L | * | 2.52 | * | 1.97 | * | * | * | * | * | | | | | |
| Molybdenum | mg/kg | 4.43 | 7.10 | ND | 5.19 | 4.92 | ND | ND | ND | ND | | | | 3500 | 3500 |
| Nickel | mg/kg | *32.4* | ***54.1*** | *35.9* | ***63.3*** | 18.9 | 17.0 | *33.0* | 16.7 | 7.74 | 20.9 | 51.6 | 110 | 200 | 2000 |
| Selenium | mg/kg | 2.35 | 1.86 | ND | 1.65 | ND | ND | ND | ND | ND | | | 1 | 10 | 100 |
| Silver | mg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND | 1 | 3.7 | 0.56 | 50 | 500 |
| Thallium | mg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND | | | | 70 | 700 |
| Vanadium | mg/kg | 45.8 | 45.4 | 50.2 | 42.8 | 29.6 | 17.5 | 50.5 | 21.7 | 16.3 | | | | 240 | 2400 |
| Zinc | mg/kg | ***611*** | *343* | *157* | *377* | ***424*** | ***498*** | 85.6 | *372* | 41.6 | 150 | 410 | 410 | 2500 | 5000 |
| Mercury | mg/kg | 0.053 | 0.084 | ND | 0.074 | 0.033 | ND | 0.049 | 0.050 | 0.076 | 0.15 | 0.71 | 0.41 | 2 | 20 |
| Total Organic Carbon | % | 0.65 | 0.98 | 0.41 | 0.67 | 0.18 | 0.56 | 0.52 | 0.5 | 0.4 | | | | | |
| Ammonia | mg/kg | 51 | 48 | 26 | 54 | 33 | 40 | 31 | 41 | 11 | | | | | |
| Total Sulfides | mg/kg | 43 | 26 | ND | 23 | 81 | 5.7 | 1.7 | 10 | ND | | | | | |
| Soluble Sulfides | mg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND | | | | | |

**Table 5 (continued)**

**Metals and General Chemistry Results**

| Analyte | Units (dry wt.) | Hilda | | | | Hope | | | | LA-2 Reference | ERL | ERM | AET | 10X STLC | TTLC (wet wt.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Top | Middle | Bottom | Comp. | Top | Middle | Bottom | Comp. | | | | | | |
| Antimony | mg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND | | | 9.3 | 150 | 500 |
| Arsenic | mg/kg | 3.97 | 5.11 | 4.52 | 4.73 | 2.19 | 3.47 | 4.93 | 3.23 | 1.88 | 8.2 | 70 | 57 | 50 | 500 |
| Barium | mg/kg | 3210 | 2420 | 549 | 5320 | 4440 | 5370 | 992 | 5490 | 76.0 | | | 48 | 1000 | 10000 |
| Barium (STLC) | mg/L | 3.55 | 12.9 | * | 8.4 | 2.92 | 15.8 | * | 5.79 | * | | | | | |
| Beryllium | mg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND | | | | 7.5 | 75 |
| Cadmium | mg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND | 1.2 | 9.6 | 2.7 | 10 | 100 |
| Chromium (Total) | mg/kg | 45.2 | *105* | 28.5 | 56.5 | 19.2 | *135* | 35.5 | 49.0 | 15.6 | 81 | 370 | 96 | 50 | 2500 |
| Chromium (STLC) | mg/L | * | 3.43 | * | 1.43 | * | 6.53 | * | * | * | | | | | |
| Cobalt | mg/kg | 3.41 | 4.34 | 4.96 | 4.51 | 1.61 | 2.51 | 6.95 | 3.03 | 3.17 | | | | 800 | 8000 |
| Copper | mg/kg | 21.4 | 17.1 | 10.2 | 12.9 | 8.24 | 28.6 | 13.7 | 16.6 | 3.90 | 34 | 270 | 390 | 250 | 2500 |
| Lead | mg/kg | 30.4 | *77.3* | 7.40 | 14.2 | 15.5 | *79.0* | 12.4 | 28.6 | 4.26 | 46.7 | 218 | 430 | 50 | 1000 |
| Lead (STLC) | mg/L | * | 1.11 | * | * | * | 3.32 | * | * | * | | | | | |
| Molybdenum | mg/kg | 2.74 | 5.03 | ND | 2.55 | 2.03 | 2.13 | ND | 1.53 | ND | | | | 3500 | 3500 |
| Nickel | mg/kg | 19.1 | *38.5* | *26.2* | *30.3* | 7.99 | 15.5 | *29.2* | 15.5 | 7.74 | 20.9 | 51.6 | 110 | 200 | 2000 |
| Selenium | mg/kg | ND | 2.53 | ND | 1.91 | ND | ND | ND | ND | ND | | | 1 | 10 | 100 |
| Silver | mg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND | 1 | 3.7 | 0.56 | 50 | 500 |
| Thallium | mg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND | | | | 70 | 700 |
| Vanadium | mg/kg | 23.8 | 40.5 | 33.0 | 40.4 | 12.4 | 14.5 | 48.4 | 20.3 | 16.3 | | | | 240 | 2400 |

## Table 5 (continued)

## General Chemistry and Metals Results

| Analyte | Units (dry wt.) | Hilda | | | | Hope | | | | LA-2 Reference | ERL | ERM | AET | 10X STLC | TTLC (wet wt.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Top | Middle | Bottom | Comp. | Top | Middle | Bottom | Comp. | | | | | | |
| Zinc | mg/kg | *379* | *287* | 87.7 | ***468*** | ***418*** | ***575*** | 134 | ***493*** | 41.6 | 150 | 410 | 410 | 2500 | 5000 |
| Mercury | mg/kg | 0.055 | ND | 0.043 | 0.033 | 0.098 | 0.145 | ND | 0.086 | 0.076 | 0.15 | 0.71 | 0.41 | 2 | 20 |
| Total Organic Carbon | % | 0.72 | 1.2 | 0.7 | 0.82 | 0.43 | 0.29 | 0.52 | 0.45 | 0.4 | | | | | |
| Ammonia | mg/kg | 39 | 100 | 31 | 39 | 15 | 19 | 24 | 15 | 11 | | | | | |
| Total Sulfides | mg/kg | 1000 | 95 | 22 | 20 | 430 | 94 | 130 | 450 | ND | | | | | |
| Soluble Sulfides | mg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND | | | | | |

*Italics* indicates values above ERL

**Bold** indicates values above ERM

Box indicates values above AET

*no measurement necessary

mg/kg – milligrams per kilogram

µg/kg – micrograms per kilogram

mg/L – milligrams per liter

ND – nondetect

wt. – weight

STLC – soluble threshold limit concentration

TTLC – total threshold limit concentration

The top stratum of the Hazel shell mound contained barium, selenium, and zinc above their AET values. Zinc was also detected at elevated levels above the ERM value and nickel was detected above the ERL value. The middle stratum contained elevated levels of chromium, barium, and selenium above the AET values and nickel above the ERM value. Arsenic, cadmium, chromium, lead, and zinc all exceeded their ERL values. The bottom stratum was relatively free of chemical contamination. Barium was the only metal found above the AET value and nickel and zinc were the only metals found elevated from the ERL value. No metals were detected over the ERM values. The composite contained two metals, barium and selenium, that exceeded AET values and four metals, cadmium, chromium, lead, and nickel that exceeded the ERL values. Only nickel exceeded the ERM value.

Barium exceeded the AET values in all strata of Platform Heidi. Zinc exceeded the AET and ERM values in the top and middle strata. Chromium was present at concentrations above the AET and ERL values in the middle stratum and the bottom stratum only contained nickel above the ERL value. The composite strata sample contained zinc at an elevated ERL value.

Barium exceeded the AET values in all strata of Platform Hilda. The AET value was also exceeded for chromium and selenium in the middle stratum, and selenium and zinc in the composite sample. ERL values were elevated for zinc in the top stratum, chromium, lead, nickel, and zinc in the middle stratum, nickel in the bottom stratum, and nickel and zinc in the composite sample.

As with the three previous sites, barium exceeded the AET values in all strata in Platform Hope. Zinc exceeded the AET and ERM values in the top and middle strata, and composite strata. Lead in the middle stratum was elevated over the ERL, as was nickel in the bottom strata.

STLC analyses were conducted on several samples that had bulk sediment metal levels found to be 10 times greater than their STLC criteria (Table 5). These include barium, chromium, and lead. These analyses indicated that the soluble level of these metals is not problematic.

*Organic Chemistry*

Results of the organic chemical results (dry weight) are tabulated in Table 6. Petroleum hydrocarbons were present in each shell mound but were dominant in the middle stratum of all four mounds. No TPH were found in the bottom stratum or in the top stratum of the Hilda or Heidi shell mounds. TRPH were found in all strata of all shell mounds and were elevated over the reference values in all strata of shell mounds Hilda and Hope, the middle stratum ofHeidi, and the top and middle strata of Hazel. PCBs were found to exceed the ERL (ERL = 22.7 micrograms per kilogram [µg/kg]) and AET (AET = 130 µg/kg) values in the top stratum of Hazel. The ERM (ERM = 180 µg/kg) and AET for PCBs were also exceeded in the top strata and composite sample of Hilda and Hope and the middle stratum of Hilda. The only pesticide detected was 4,4'-DDE.

**Table 6. Bulk Sediment Organics Results**

| Analyte | Units (dry wt.) | Hazel | | | | Heidi | | | | LA-2 Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Top | Middle | Bottom | Comp. | Top | Middle | Bottom | Comp. | |
| Total TPH | mg/kg | 48 | 130 | ND | 100 | ND | 250 | ND | 120 | ND |
| TRPH | mg/kg | 280 | 440 | 30 | 490 | 49 | 330 | 41 | 280 | 68 |
| Aroclor-1254[a] | µg/kg | ***160*** | ***150*** | ND | *130* | ND | ND | ND | ND | ND |
| 4,4'-DDE[b] | µg/kg | ND | ND | ND | ND | 0.66 | ND | ND | ND | *2.9* |
| Phenols | mg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Phthalates | mg/kg | 0.13 | ND | ND | ND | 0.06 | ND | ND | ND | ND |
| Organotins | µg/kg | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| VOCs | µg/kg | ND | 9075 | 6671 | 10399 | ND | 13963 | 0.05 | 7246 | ND |
| PAHs | mg/kg | 1.3 | 1.7 | ND | 1.1 | ND | 1.88 | ND | 0.98 | ND |
| Analyte | Units (dry wt.) | Hilda | | | | Hope | | | | LA-2 Reference |
| | | Top | Middle | Bottom | Comp. | Top | Middle | Bottom | Comp. | |
| Total TPH | mg/kg | ND | 100 | ND | ND | 8.4 | 86 | ND | ND | ND |
| TRPH | mg/kg | 2400 | 3300 | 290 | 1200 | 360 | 800 | 160 | 570 | 68 |
| Aroclor-1254[a] | µg/kg | ***220*** | ***180*** | ND | ***210*** | ***1600*** | *56* | ND | ***400*** | ND |
| 4,4'-DDE[b] | µg/kg | ND | ND | ND | ND | ND | ND | ND | ND | *2.9* |
| Phenols | mg/kg | ND | ND | ND | ND | ND | 0.032 | ND | ND | ND |
| Phthalates | mg/kg | 0.35 | ND | ND | ND | ND | 0.039 | ND | ND | ND |
| Organotins | µg/kg | 5.6 | ND | ND | 1.83 | 8.2 | 13.6 | ND | 5.17 | ND |
| VOCs | µg/kg | 237.5 | 5507.8 | 35 | 714.7 | 948.2 | 3429.6 | 38.5 | 1631 | ND |
| PAHs | mg/kg | ND | 0.39 | ND | 0.15 | 0.078 | 0.387 | ND | ND | ND |

*Italics* indicates values above ERL (PCB = 22.7 µg/kg) (4,4'-DDE = 2.2 µg/kg)
**Bold** indicates values above ERM (PCB = 180 µg/kg)
Box indicates values above AET (PCB = 130 µg/kg)
[a]Aroclor-1254 was the only PCB detected above the reporting limit.
[b]DDE was the only pesticide detected above the reporting limit.
mg/kg – milligrams per kilogram
µg/kg – micrograms per kilogram
ND – nondetect
Comp. – composite
Wt. – weight
TPH – total petroleum hydrocarbons
TRPH – total recoverable petroleum hydrocarbons
PCB – polychlorinated biphenyl
DDE – 1,1-dichloro-2,2-bis(chlorophenyl) ethylene
VOCs – volatile organic compounds
PAHs – polycyclic aromatic hydrocarbons

The 4,4'-DDE ERL (2.2 μg/kg) was not exceeded in any of the shell mound sediment samples analyzed.

Phenols were only detected in the middle stratum of the Hope shell mound. They were elevated when compared to the reference sample, which did not contain any phenols. Phthalates were detected in the top strata of the Hazel, Heidi, and Hilda and the middle stratum of the Hope shell mounds. No phthalates were found in the bottom stratum or the reference sediment. Organotins were found in the form of tributyltin in the top strata of Hilda and Hope and also the middle stratum of Hope. No organotins were detected in the Hazel or Heidi shell mounds or the reference sediments. The reference sediment contained some TRPH and the pesticide 4,4'-DDE, which was also detected above the ERL. Original chemistry reports are included in Appendix E.

Two PAHs, naphthalene and pyrene were detected in the shell mound Hazel sediment. The top stratum contained pyrene while the middle stratum and composite sample contained naphthalene. Naphthalene was over its ERL. None of the strata contained total PAH amounts that exceeded the ERL or ERM values. Heidi contained only two PAHs, naphthalene and phenanthrene. Both PAHs were found in the middle stratum and composite sample and all exceeded the ERL but not the ERM or AET values. The total PAHs, however, did not exceed the ERL or ERM.

Phenanthrene was the only PAH detected in Platform Hilda. It was found in the middle stratum and composite sample and exceeded the ERL in the middle stratum. The total PAHs, however, did not exceed the ERL or ERM. A total of five PAHs were detected in the Platform Hope sediment. All five were found in the middle stratum and only one, pyrene, was found in the top stratum. Of the middle stratum, three of the five analytes, naphthalene, acenaphthene, and fluorene, exceeded the ERL while phenanthrene and pyrene did not. The total PAHs did not exceed either the ERL or ERM. No PAHs were detected in the reference sediment.

The volatile organic contaminants benzene, toluene, and xylene were detected in all four test sediments. Low levels of acetone were also detected. The EPA Office of Solid Waste and Environmental Response (OSWER) has published Ecotox Thresholds (ETs) that are intended to be used for screening contaminants at Comprehensive Environmental Response, Compensation, and Liability Act sites (CERCLA) (Jones et al. 1996). The ETs are sediment quality benchmarks (SQBs) that were derived using the equilibrium partitioning method. OSWER has published SQBs for three volatile organics detected in the shell mound sediment. These are toluene (670 μg/kg), 1,2,4-trichlorobenzene (9,200 μg/kg), and m-xylene (25 μg/kg). Each of these concentrations is in dry weight.

Elevated levels of benzene, toluene, and xylene were detected in the middle and bottom strata of Platform Hazel sediment compared to the reference sediment. No detected levels of volatile organics were found in the top stratum. The concentration level in the sediment composite for the three volatile organics that have SQBs, toluene, 1,2,4-trichlorobenzene, and m-xylene, are 400 μg/kg, nondetect and 2,200 μg/kg (p/m-

xylene), respectively. Elevated levels of benzene, toluene, and xylene were detected in the middle and bottom strata of Platform Heidi sediment compared to the reference sediment. Low levels of acetone (bottom stratum only), carbon disulfide (composite only), and 1,2-dichloropropane (composite only) were also detected. No detected levels of volatile organics were found in the top stratum. The concentration level in the sediment composite for the three volatile organics that have SQBs, toluene, 1,2,4-trichlorobenzene, and m-xylene, are 37 μg/kg, nondetect, and 490 μg/kg (p/m-xylene), respectively.

Elevated levels of benzene, toluene, and xylene were detected in the top, middle and bottom strata of Platform Hilda sediment compared to the reference sediment. Low levels of acetone (bottom stratum only) and carbon disulfide (middle stratum only) were also detected. The concentration level in the sediment composite for the three volatile organic compounds that have SQBs, toluene, 1,2,4-trichlorobenzene, and m-xylene, are 12 μg/kg, nondetect, and 100 μg/kg (p/m-xylene), respectively. Elevated levels of benzene, toluene, and xylene were detected in the middle stratum of Platform Hope sediment compared to the reference sediment. Low levels of acetone (middle and bottom strata) and carbon disulfide (top stratum only) were also detected. The concentration level in the sediment composite for the three volatile organics that have SQBs, toluene, 1,2,4-trichlorobenzene, and m-xylene, are 17 μg/kg, 360 μg/kg, 64 μg/kg (p/m-xylene), respectively.

No volatile organic contaminants were detected in the reference sediment.

## 4.3 BIOASSAY RESULTS

Raw toxicity data are included in Appendix F and bioaccumulation data are included in Appendix G.

### 4.3.1 Solid Phase Bioassay Results

Solid phase toxicity tests included amphipod (*Ampelisca abdita*) and mysid shrimp (*Americamysis bahia*) protocols. The first amphipod test was repeated because control survival was 86 percent compared to the *Green Book* requirement of 90 percent control survival. The second test met acceptability criteria with an average control survival of 95 percent.

As shown in Table 7 the Heidi, Hazel, and Hilda shell mound sediments all demonstrated a statistically significant reduction in mysid shrimp survival (and was more than 10 percent less than the reference site survival level). Exposure to all four sediment composites resulted in statistically significant (and more than 20 percent below the reference site survival level) amphipod mortality.

Laboratory measures taken to mitigate against the potential toxic effects of both ammonia and sulfides (i.e., naturally occurring substances that could be toxic at high concentrations) are discussed in the next section.

**Table 7**

**Solid Phase Toxicity Results**

| Site | Amphipod Average Survival Round 1 (%) | Amphipod Average Survival Round 2 (%) | Mysid Average Survival (%) |
|---|---|---|---|
| Control | 86 | 95 | 92 |
| Reference | 87 | 98 | 96 |
| Hazel | 24* | 33* | 84* |
| Heidi | 13* | 62* | 70* |
| Hilda | 13* | 66* | 82* |
| Hope | 25* | 61* | 86 |

*statistically significant

*Ammonia and Sulfides*

Naturally occurring ammonia and sulfide levels can contribute to the toxicity observed in bioassay tests conducted on sediment samples, particularly amphipod tests. Amphipods live in the sediment and are exposed to dissolved ammonia and sulfides in the porewater.

Prior to initiating any tests for this study, a porewater sample was collected after centrifuging test sediment and collecting the water from the top of the centrifuge tube. This sample was analyzed for total ammonia. The results for Hazel, Heidi, Hilda, and Hope were 26.6 milligrams per liter (mg/L), 18.4 mg/L, 43.7 mg/L, and 25.7 mg/L, respectively. The recommended maximum level for total ammonia is $\leq$30 mg/L ($\leq$0.4 mg/L unionized ammonia at pH 7.7) (Wagner, et al. 1999).

To mitigate for the potentially confounding effects of ammonia and sulfide toxicity, several measures were taken in the bioassay laboratory during the setup of the first amphipod test. The day before the initiation of the solid phase tests, sediment and water were added to each test chamber. Prior to introducing test organisms into the test chambers, the chambers were permitted to equilibrate overnight. The next day, the overlying water was completely drained from each test chamber and replaced with clean water. Organisms were then added. Another complete water change was made the following day.

The results of the first amphipod test indicated highly significant amphipod toxicity for all test site sediments (13 to 25 percent survival). In addition, the control survival for the first test (86 percent) fell short of the 90 percent minimum requirement and therefore needed to be repeated.

Since several weeks had elapsed from the time of sediment collection, there was additional concern over the buildup of ammonia and sulfides in the samples being held

in the 4ºC coldroom. Prior to re-testing the amphipods, additional ammonia and sulfide reduction measures were conducted. The second setup scenario was as follows:

1. Test sediment samples were centrifuged, and the porewater was sent to Calscience for dissolved sulfide analyses.
2. Additional porewater was collected from the stored sample jars and analyzed for ammonia in AMEC's bioassay laboratory.
3. Sediment and water were added to the test chambers and to an additional four surrogate containers.
4. After approximately 4 hours, a complete water change was made, and porewater was collected from a surrogate container and analyzed for total ammonia.
5. The containers were permitted to equilibrate overnight.
6. The following day, another complete water change was made, and another porewater sample was collected from a surrogate chamber and analyzed for total ammonia.
7. Approximately 4 to 5 hours later, another complete water change was made, and a porewater sample was collected from a surrogate chamber and analyzed for total ammonia.
8. After this water change, all porewater ammonia levels were found to be below 30 mg/L ($\leq$0.4 mg/L unionized ammonia at pH 7.7) and the test was initiated by adding organisms.
9. During the 10-day test period additional water changes were made on Day 1 and Day 6 .
10. Porewater samples were collected at the end of the 10-day test period from a surrogate chamber and analyzed for total ammonia.

The results of the ammonia analyses conducted on the porewater samples from the second amphipod test are presented in Table 8.

Based on these results, it is possible that a portion of the toxicity observed in the first amphipod toxicity test was attributable to ammonia levels in the porewater. Test survival in the retest was much higher, but it was still statistically significant compared to reference survival. By increasing the number of water changes, the ammonia in the porewater was reduced to an acceptable level. By the end of the test period, the ammonia levels in the porewater were significantly lower. It should be noted, by conducting numerous water changes, other potential contaminants of concern in the sediment might have also been reduced in concentration.

Dissolved sulfides are also a concern when interpreting amphipod survival results. There is no recommended criteria level for *Ampelisca*, but approximately 1.5 mg/L to 2 mg/L is used for other amphipod species. To assess the potential impact of dissolved sulfides on amphipod survival, porewater samples were collected and sent to Calscience for analysis. The results indicate Heidi had a dissolved sulfide level of 0.3

**Table 8**

**Total and Unionized Ammonia Levels in Porewater**

| Site | Total Ammonia level in stored samples (mg/L) | Total Ammonia level following first water change (mg/L) | Total Ammonia level following second water change (mg/L) | Total Ammonia level following third water change (mg/L) | Unionized Ammonia Level following third water change (mg/L at pH 7.7) | Total Ammonia level at test termination (mg/L) |
|---|---|---|---|---|---|---|
| Hazel | 27.2 | 30.8 | 22.9 | 16.8 | 0.24 | 2.9 |
| Heidi | 38.0 | 30.0 | 21.7 | 17.0 | 0.24 | 7.4 |
| Hilda | 57.5 | 42.3 | 32.8 | 28.9 | 0.41 | 7.9 |
| Hope* | not enough sample | not enough sample | not enough sample | not enough sample | not enough sample | 0.6 |

*Not enough sample was collected in the field to be able to repeat the amphipod test and analyze surrogate chambers for ammonia levels. The tests performed on the other three sediments, however, are indicative of what occurred in Platform Hope sediment. In addition, Platform Hope sediment had the lowest ammonia levels (0.6 mg/L) upon termination of the 10-day test.

mg/L, while the three other sites were all nondetect (<0.05). In addition, a memorandum titled *Technical Panel Recommendations Concerning Use of Acute Amphipod Tests in Evaluation of Dredged Material* (Tudor 1993) states "Hydrogen sulfide toxicity is not believed to be a problem if dissolved oxygen levels are maintained in the overlying waters." The overlying water dissolved oxygen levels for this test were maintained above the acceptable level.

The potential impact of ammonia on mysid shrimp in the solid phase test can be evaluated by analyzing the ammonia levels in the overlying water of the test chamber (i.e., where the organisms reside). The highest concentration of total ammonia was measured in the overlying waters of the Hilda test (8.9 mg/L). This level of total ammonia equates to a concentration of unionized ammonia (i.e., the toxic form of ammonia) of 0.82 mg/L at a temperature of 26.8$^{o}$C and a pH of 8.2. The $LC_{50}$ for unionized ammonia for mysid shrimp has been reported to be 1.47 to 3.41 mg/L (EPA 1989). Platform Hilda sediment had the highest total ammonia level (8.4 mg/L) in the overlying water at the termination of the 10-day test. This equates to a unionized ammonia level of 0.24 mg/L at a temperature of 25.3$^{o}$C and a pH of 7.74. It should be noted that the total ammonia level in the overlying water of the reference sediment chambers was 7.9 mg/L (0.44 mg/L of unionized ammonia at 25.7$^{o}$C and pH 7.97). These results indicate that ammonia was most likely not a contributing factor in the toxicity observed in the solid phase mysid shrimp tests.

AMEC's Bioassay Laboratory has also conducted a mysid shrimp reference test with ammonium chloride to establish in-house effect concentrations ($EC_{50}$) for ammonia. The results of these tests indicated that the no observed effect concentration (NOEC)

for total and unionized ammonia following a 24-hour exposure was 26 mg/L and 1.8 mg/L, respectively. The 96-hour NOEC for total and unionized ammonia was determined to be 29 mg/L and 1.6 mg/L, respectively. The reference test was conducted at 25°C and had a pH range of 7.94 to 8.25. These results also indicate that ammonia was unlikely to have contributed to the statistically significant toxicity observed in the mysid solid phase test.

### 4.3.2 Suspended-particulate Phase Bioassay Results

The results of the suspended-particulate phase tests performed using silversides (*Menidia beryllina*), mysid shrimp (*Americamysis bahia*), and bivalve larvae (*Mytilus edulis*) are shown in Table 9. No significant toxicity was observed in the silverside or mysid shrimp tests. Only the 100 percent concentration for the Hazel bivalve test resulted in statistically significant abnormalities, albeit only a minor difference when compared to the control (80 percent normal development versus the control level of 85 percent). All tests had $LC_{50}$s (mysid shrimp and silversides) and $EC_{50}$ (bivalve larvae) values greater than 100 percent.

**Table 9. Suspended-particulate Phase Toxicity Results**

| Site | Conc. (%) | Menidia Average Survival (%) | Mysid Average Survival (%) | Bivalve Larvae Average Normal Development (%) |
|---|---|---|---|---|
| Control | 0 | 100 | 100 | 85 |
| Hazel | 10 | 96 | 100 | 86 |
| | 50 | 100 | 100 | 88 |
| | 100 | 100 | 100 | 80* |
| Control | 0 | 100 | 100 | 85 |
| Heidi | 10 | 96 | 98 | 83 |
| | 50 | 98 | 96 | 89 |
| | 100 | 92 | 96 | 89 |
| Control | 0 | 100 | 98 | 83 |
| Hilda | 10 | 92 | 98 | 83 |
| | 50 | 94 | 98 | 81 |
| | 100 | 98 | 96 | 80 |
| Control | 0 | 100 | 98 | 83 |
| Hope | 10 | 100 | 96 | 85 |
| | 50 | 96 | 96 | 83 |
| | 100 | 100 | 98 | 90 |

Conc – concentration

*statistically significant

### 4.3.3 Bioaccumulation Phase Bioassay Results

*Metals Bioaccumulation*

Metals bioaccumulation results are summarized in Tables 10 and 11 for clams and worms, respectively. Detailed data tables, statistical analysis results, and the laboratory chemistry report are contained in Appendix G.

Platform Hazel

Barium, chromium, and lead were present at statistically elevated concentrations in the test clam tissue compared to the reference tissue levels. Barium and molybdenum concentrations were statistically elevated in worm tissue. Concentrations of other heavy metals in test organisms were not statistically different from those in the respective clam and worm reference tissues. The chromium, lead, and molybdenum concentrations were only slightly (a maximum of 1.6 times) above the corresponding reference tissue levels. The statistical significance of these results was due, in part, to the small variance in the reference tissue data and they are not considered ecologically significant. In contrast, the test clam tissues had an average barium concentration (515 mg/kg) that was 61 times higher than the reference clam tissue (8.4 mg/kg). Similarly, the test worm tissue had an average barium concentration (233 mg/kg) that was 31 times higher than the reference tissue (7.5 mg/kg).

Platform Heidi

Barium was present at statistically elevated levels in test clam tissue compared to the reference tissue levels. Barium and molybdenum concentrations were also statistically elevated in the test worm tissue. Concentrations of other heavy metals in test organisms were not statistically different from those in the respective clam and worm reference tissues. Average molybdenum concentrations in worm tissues were only slightly higher (1.5 times the reference tissue level) than that of the reference tissue level. The statistical significance of these results was due in part to the small variance associated with the reference tissue data, and they are not considered ecologically significant. In contrast, test clam tissues had an average barium concentration (162 mg/kg) that was 19 times higher than the reference tissue concentration (8.4 mg/kg). Similarly, test worm tissues had an average barium concentration (205 mg/kg) that was 27 times higher than the reference tissue level (7.5 mg/kg).

Platform Hilda

Barium was present at statistically elevated levels in the test clam tissue compared to the reference tissue levels. Barium and molybdenum concentrations also were statistically elevated in worm tissue. Concentrations of all other heavy metals in the test clam and worm were not statistically different from corresponding concentrations in the reference tissues. Average molybdenum concentrations in worm tissue were only slightly (1.2 times) higher than that of the reference tissue level. Statistical significance was due in part to the small variability in the reference tissue data, and this difference is not ecologically important. In contrast, the average barium concentration in test clam

**Table 10. Average (± std. dev.) Metal Concentrations in Test and Reference Clam Tissue**

| Analyte | Units (dry wt) | Ref. Avg. (± std. dev.) | Hazel Avg. (± std. dev.) | Heidi Avg. (± std. dev.) | Hilda Avg. (± std. dev.) | Hope Avg. (± std. dev.) |
|---|---|---|---|---|---|---|
| Antimony | mg/kg | 0.20 (0.03) | 0.19 (0.05) | 0.19 (0.02) | 0.16 (0.02) | 0.19 (0.05) |
| Arsenic | mg/kg | 17.3 (2.26) | 18.2 (3.17) | 18.7 (0.94) | 16.0 (0.72) | 15.5 (2.26) |
| Barium | mg/kg | 8.4 (4.54) | 515* (377) | 162* (48.6) | 269* (246) | 320* (139) |
| Beryllium | mg/kg | ND | ND | ND | ND | ND |
| Cadmium | mg/kg | 0.24 (0.03) | 0.24 (0.03) | 0.22 (0.03) | 0.23 (0.01) | 0.23 (0.03) |
| Chromium | mg/kg | 6.4 (0.61) | 7.5* (0.87) | 6.4 (1.02) | 6.6 (0.36) | 6.9 (0.56) |
| Cobalt | mg/kg | 0.92 (0.04) | 0.94 (0.08) | 0.95 (0.05) | 0.98 (0.07) | 0.98 (0.06) |
| Copper | mg/kg | 12.1 (1.81) | 10.7 (0.54) | 10.0 (1.04) | 8.4 (1.7) | 7.7 (0.62) |
| Lead | mg/kg | 1.03 (0.5) | 1.64* (0.57) | 0.71 (0.12) | 0.78 (0.25) | 1.04 (0.16) |
| Mercury | mg/kg | 0.07 (0.01) | 0.07 (0.02) | 0.06 (0.01) | 0.06 (0.01) | 0.06 (0.01) |
| Molybdenum | mg/kg | 4.9 (0.52) | 5.3 (0.52) | 4.7 (0.61) | 3.5 (1.25) | 2.6 (0.31) |
| Nickel | mg/kg | 3.0 (0.33) | 2.8 (0.26) | 2.3 (0.23) | 2.3 (0.32) | 2.3 (0.25) |
| Selenium | mg/kg | 2.5 (0.18) | 2.4 (0.14) | 2.5 (0.11) | 2.5 (0.12) | 2.5 (0.24) |
| Silver | mg/kg | 0.31 (0.08) | 0.23 (0.03) | 0.25 (0.04) | 0.19 (0.05) | 0.21 (0.06) |
| Thallium | mg/kg | ND | ND | ND | ND | ND |
| Vanadium | mg/kg | 1.6 (0.11) | 1.5 (0.28) | 1.5 (0.07) | 1.8 (0.22) | 1.5 (0.13) |
| Zinc | mg/kg | 85.1 (6.15) | 78.7 (14.3) | 77.4 (6.21) | 77.3 (9.15) | 74.7 (6.15) |

*statistically significant (p≤0.05); n=5

**Table 11. Average (± std. dev.) Metal Concentrations in Test and Reference Worm Tissue**

| Analyte | Units (dry wt) | Ref. Avg. (± std. dev.) | Hazel Avg. (± std. dev.) | Heidi Avg. (± std. dev.) | Hilda Avg. (± std. dev.) | Hope Avg. (± std. dev.) |
|---|---|---|---|---|---|---|
| Antimony | mg/kg | 0.12 (0.06) | 0.07 (0.03) | 0.07 (0.02) | 0.10 (0.05) | 0.06 (0.01) |
| Arsenic | mg/kg | 13.1 (1.29) | 13.2 (0.74) | 11.5 (1.11) | 11.7 (1.19) | 12.3 (1.12) |
| Barium | mg/kg | 7.5 (2.18) | 233* (141) | 205* (143) | 318* (293) | 118* (68) |
| Beryllium | mg/kg | ND | ND | ND | ND | ND |
| Cadmium | mg/kg | 0.29 (0.04) | 0.25 (0.05) | 0.26 (0.02) | 0.24 (0.03) | 1.47 (2.03) |
| Chromium | mg/kg | 5.2 (1.11) | 6.0 (0.27) | 5.1 (1.51) | 6.4 (2.04) | 7.1 (3.04) |
| Cobalt | mg/kg | 0.55 (0.03) | 0.42 (0.07) | 0.47 (0.08) | 0.45 (0.09) | 0.40 (0.08) |
| Copper | mg/kg | 5.5 (0.19) | 3.4 (0.27) | 4.0 (0.59) | 3.9 (0.57) | 4.2 (1.18) |
| Lead | mg/kg | 0.72 (0.07) | 1.00 (0.35) | 0.72 (0.10) | 1.16 (1.02) | 0.76 (0.10) |
| Mercury | mg/kg | 0.06 (0.01) | 0.07 (0.03) | 0.05 (0.01) | 0.05 (0.01) | 0.10* (0.04) |
| Molybdenum | mg/kg | 1.1 (0.03) | 1.4* (0.05) | 1.7* (0.57) | 1.3* (0.01) | 1.2* (0.06) |
| Nickel | mg/kg | 1.5 (0.16) | 1.1 (0.13) | 1.3 (0.34) | 1.5 (0.53) | 1.1 (0.40) |
| Selenium | mg/kg | 2.7 (0.26) | 2.3 (0.17) | 2.4 (0.28) | 2.3 (0.27) | 2.1 (0.16) |
| Silver | mg/kg | 0.15 (0.09) | 0.10 (0.03) | 0.15 (0.16) | 0.12 (0.06) | 0.26 (0.21) |
| Thallium | mg/kg | ND | ND | ND | ND | ND |
| Vanadium | mg/kg | 2.0 (0.35) | 1.4 (0.08) | 1.9 (0.49) | 2.2 (0.87) | 1.4 (0.07) |
| Zinc | mg/kg | 99 (35.1) | 86 (41.3) | 107 (49.5) | 82 (50) | 59 (14) |

*statistically significant (p≤0.05); n=5 (n=4 for Hope)

tissue (269 mg/kg) was 32 times higher than the average concentration in the reference tissue (8.4 mg/kg), and test worm tissue contained average barium concentrations (318 mg/kg) that were 42 times higher than those in reference tissue (7.5 mg/kg).

Platform Hope

Barium was statistically higher in Hope clam tissue than in reference tissues. Barium, mercury, and molybdenum concentrations also were statistically elevated in worm tissue. Concentrations of mercury (0.10 mg/kg) and molybdenum (1.2 mg/kg) in worm tissue were only slightly (1.7 and 1.1 times the reference tissue levels, respectively) above those in the reference tissue; statistical significance in this case is not considered to be ecologically significant. In contrast, average barium concentrations in test clam tissue (320 mg/kg) were 38 times higher than the reference tissue (8.4 mg/kg). Similarly, average barium concentrations in the test worm tissue (118 mg/kg) were 16 times higher than average barium concentrations in the reference tissue (7.5 mg/kg).

*Organic Bioaccumulation*

Organic bioaccumulation results are summarized in Tables 12 and 13 for clams and worms, respectively. Detailed data tables, statistical analysis results, and the laboratory chemistry report are contained in Appendix G.

Platform Hazel

Detectable levels of PCBs were not present in either clam or worm tissue exposed to Hazel shell mound sediment. The only pesticides detected in clam tissues were DDTs and related metabolites. No pesticides were detected in worm tissue. The total pesticide level (the sum of all detected pesticides) in Hazel clam tissue was 90.5 μg/kg, which is approximately equal to that of the average reference tissue level (82.9 μg/kg). DDT is a widespread contaminant in sediment in the southern California Bight. Low level concentrations of DDT in Bight sediment samples and subsequent low-level bioaccumulation in test organisms are common in dredged material characterization studies. Concentrations of chlorinated pesticides and PCBs in test tissues were not statistically different from those in reference tissues.

Concentrations of PAHs in Hazel clam tissue ranged from nondetectable (ND) to 42.6 μg/kg for phenanthrene, and in worm tissue from ND to 446 μg/kg for naphthalene. The total PAH (i.e., sum of detected PAH compounds excluding alkyl-substituted naphthalenes and phenanthrenes) concentrations were 162 μg/kg and 716 μg/kg for clam and worm tissue, respectively. The reference tissue concentration for both clams and worms were approximately 20 μg/kg and 27 μg/kg, respectively. Therefore, the average total PAH concentration in test clam tissue was 8 times higher than the reference tissue level, and the average concentration in test worm tissues was 27 times higher than the reference worm tissue level. The total PAH levels in both clams and worms were significantly higher than reference tissue levels.

Concentrations of specific naphthalene and phenanthrene isomers in test worm and clam tissues were quantified in addition to the standard list of parent PAH compounds.

Average concentrations of methyl-substituted naphthalenes (1-methyl- and 2-methyl-) reached 1,175 μg/kg and 1,528 μg/kg, respectively, in test worm tissues and up to 37.6 μg/kg and 61.2 μg/kg, respectively, in clam tissues. Concentrations of 1-methylphenanthrene, 2,6-dimethyl-naphthalene, and 2,3,5-trimethylnaphthalene were also present at concentrations exceeding 100 μg/kg in test worm and clam tissues in individual replicates. Concentrations of these compounds were less than 30 μg/kg in the corresponding reference tissues.

**Table 12. Average PCB, Pesticide, and PAH Concentrations (±std. dev.) in Test and Reference Clam Tissue**

| Analyte | Units (dry wt.) | Ref. Avg (±std. dev.) | Hazel Avg. (±std. dev.) | Heidi Avg (±std. dev.) | Hilda Avg. (±std. dev.) | Hope Avg. (±std. dev.) |
|---|---|---|---|---|---|---|
| Total PCBs | µg/kg | ND | ND | ND | ND | ND |
| Total Pesticides | µg/kg | 82.9 (34.3) | 90.5 (16.3) | 24.4 (-) | 23.7 (14.5) | 4.3 (-) |
| Acenaphthene | µg/kg | ND | 6.7 (0.81) | 4.08 (1.17) | 5.1 (1.36) | 3.3 (1.63) |
| Acenaphthylene | µg/kg | ND | 2.8 (0.57) | 2.9 (0.92) | 1.9 (-) | 1.5 (-) |
| Anthracene | µg/kg | ND | 3.8 (0.90) | 4.5 (1.65) | 5.8 (2.76) | 6.8 (3.65) |
| Benz[a]anthracene | µg/kg | 22.4 (6.72) | 18.5 (18.9) | 8.0 (3.0) | 13.6 (6.99) | 7.1 (4.31) |
| Benzo[a]pyrene | µg/kg | ND | ND | ND | ND | ND |
| Benzo[b]fluoranthene | µg/kg | ND | ND | ND | ND | ND |
| Benzo[g,h,i]perylene | µg/kg | ND | ND | ND | ND | ND |
| Benzo[k]fluoranthene | µg/kg | ND | ND | ND | ND | ND |
| Chrysene | µg/kg | 4.6 (-) | 28.1 (17.61) | 3.6 (1.62) | 35.5 (17.17) | 7.5 (6.20) |
| Dibenz[a,h]anthracene | µg/kg | ND | ND | ND | ND | ND |
| Fluoranthene | µg/kg | ND | 16.5 (2.90) | 5.6 (1.56) | 16.9 (7.05) | 22.6 (11.76) |
| Fluorene | µg/kg | ND | 16.9 (6.58) | 15.0 (1.85) | 14.9 (3.65) | 8.325 (2.99) |
| Indeno[1,2,3-c,d]pyrene | µg/kg | ND | ND | ND | ND | ND |
| Naphthalene | µg/kg | 6.0 (1.38) | 13.2 (5.59) | 9.9 (1.03) | 6.3 (0.87) | 6.1 (1.7) |
| Phenanthrene | µg/kg | 5.5 (-) | 42.6 (18.11) | 76.0 (7.55) | 88.1 (24.87) | 39.7 (13.89) |
| Pyrene | µg/kg | ND | 28.1 (15.39) | 13.2 (1.87) | 37.1 (19.07) | 27.3 (14.17) |
| Total PAHs | µg/kg | 20 (17.5) | 162* (81.6) | 130* (16.3) | 220* (85.8) | 121* (57.2) |
| 1-Methylnaphthalene | µg/kg | 4.1 (1.41) | 37.6 (17.4) | 15.5 (6.41) | 12.7 (2.80) | 8.0 (1.26) |
| 1-Methylphenanthrene | µg/kg | ND | 40.0 (24.1) | 68.8 (14.1) | 88.9 (22.6) | 31.7 (18.6) |
| 2,3,5-Trimethylnaphthalene | µg/kg | ND | 76.4 (43.3) | 53.2 (20.2) | 62.0 (22.6) | 31.9 (19.5) |
| 2,6-Dimethylnaphthalene | µg/kg | ND | 155 (50.7) | 84.3 (18.9) | 60.1 (17.6) | 24.0 (6.54) |
| 2-Methylnaphthalene | µg/kg | 6.2 (1.16) | 61.2 (40.3) | 38.2 (8.32) | 17.9 (3.13) | 10.4 (2.73) |
| Total Methynaphthalenes | µg/kg | 8.2 (5.1) | 371 (162) | 260 (55.9) | 240 (55.9) | 105 (34.6) |

(-) indicates no standard deviation (detected in only 1 replicate) *statistically significant (p≤0.05)

**Table 13. Average PCB, Pesticide, and PAH Concentrations (±std. dev.) in Test and Reference Worm Tissue**

| Analyte | Units (dry wt.) | Ref. Avg. (±std. dev.) | Hazel Avg. (±std. dev.) | Heidi Avg. (±std. dev.) | Hilda Avg. (±std. dev.) | Hope Avg. (±std. dev.) |
|---|---|---|---|---|---|---|
| Total PCBs | µg/kg | ND | ND | ND | ND | ND |
| Total Pesticides | µg/kg | ND | ND | ND | ND | ND |
| Acenaphthene | µg/kg | ND | 15.4 (3.46) | ND | 14.7 (6.80) | 15.5 (0.21) |
| Acenaphthylene | µg/kg | ND | 13.0 (0.28) | ND | 1.3 (-) | 7.3 (-) |
| Anthracene | µg/kg | 4.2 (-) | 10.5 (2.97) | ND | 10.6 (4.48) | 21.5 (3.46) |
| Benz[a]anthracene | µg/kg | 9.7 (4.29) | 19.8 (17.34) | ND | 25.3 (18.25) | 20.8 (1.56) |
| Benzo[a]pyrene | µg/kg | ND | ND | ND | ND | ND |
| Benzo[b]fluoranthene | µg/kg | ND | ND | ND | ND | ND |
| Benzo[g,h,i]perylene | µg/kg | ND | ND | ND | ND | ND |
| Benzo[k]fluoranthene | µg/kg | ND | ND | ND | ND | ND |
| Chrysene | µg/kg | 14.6 (8.27) | 49.6 (20.7) | ND | 60.4 (22.9) | 17.0 (2.26) |
| Dibenz[a,h]anthracene | µg/kg | ND | ND | ND | ND | ND |
| Fluoranthene | µg/kg | ND | 7.7 (-) | ND | 13.0 (4.32) | 15.6 (0.35) |
| Fluorene | µg/kg | ND | 20.8 (9.33) | ND | 21.1 (15.2) | 12.5 (0.14) |
| Indeno[1,2,3-c,d]pyrene | µg/kg | ND | ND | ND | ND | ND |
| Naphthalene | µg/kg | 9.8 (3.03) | 446.4 (136.3) | 184.1 (90.9) | 97.6 (34.2) | 41.2 (13.7) |
| Phenanthrene | µg/kg | 7.8 (2.79) | 189 (23.2) | 471 (187.4) | 348 (109.2) | 203 (78.4) |
| Pyrene | µg/kg | ND | 10.3 (3.18) | ND | 30.5 (13.0) | 13.4 (2.05) |
| Total PAHs | µg/kg | 27 (14.8) | 716* (103) | 655* (259) | 569* (174) | 324* (141) |
| 1-Methylnaphthalene | µg/kg | 12.5 (4.20) | 1175 (313) | 428 (218) | 217 (25.5) | 142 (39.7) |
| 1-Methylphenanthrene | µg/kg | ND | 33.0 (6.58) | 48.0 (-) | 93.7 (33.2) | 37.0 (4.7) |
| 2,3,5-Trimethylnaphthalene | µg/kg | 10.0 (-) | 77.3 (38.3) | 122 (39.4) | 78.3 (30.4) | 44.5 (4.1) |
| 2,6-Dimethylnaphthalene | µg/kg | 6.3 (4.81) | 514 (130) | 411 (144) | 189 (46.6) | 114 (24.7) |
| 2-Methylnaphthalene | µg/kg | 18.2 (7.11) | 1528 (339) | 875 (424) | 374 (116) | 155 (61.7) |
| Total Methynaphthalenes | µg/kg | 35.2 (15.9) | 3293 (738) | 1823 (736) | 907 (155) | 427 (192) |

(-) indicates no standard deviation (detected in only 1 replicate) *statistically significant (p≤0.05)

## Platform Heidi

PCBs were not detected in either clam or worm tissue exposed to Heidi sediment. The only pesticides detected in clam tissues were DDT and metabolites, whereas no

pesticides were detected in worm tissue. The total pesticide level in Heidi shell mound clam tissue was 25.4 μg/kg, which is approximately 3 times lower than the reference level (82.9 μg/kg). Concentrations of chlorinated pesticides and PCBs in test tissues were not statistically different from those in reference tissues.

Concentrations of PAHs in Heidi clam tissue ranged from ND to 76.0 μg/kg for phenanthrene, and from ND to 471 μg/kg for naphthalene in worm tissue. The average total PAH levels were 130 μg/kg and 655 μg/kg for test clam and worm tissue, respectively. The reference tissue concentrations for both clams and worms were approximately 20 and 27 μg/kg, respectively. The total PAH level in Heidi shell mound tissue was 7 times higher than the reference tissue level in clam tissue, and concentrations in test worm tissues were 24 times higher than the reference tissue level. The total PAH levels in both test clams and worms were significantly higher than reference tissue levels.

Average concentrations of methyl-substituted naphthalenes (1-methyl- and 2-methyl-) reached 428 μg/kg and 875 μg/kg, respectively, in test worm tissues and up to 26 μg/kg and 50 μg/kg, respectively, in clam tissues. Concentrations of 1-methylphenanthrene, 2,6-dimethylnaph-thalene, and 2,3,5-trimethylnaphthalene were also present at concentrations exceeding 100 μg/kg in the test worm and clam tissues in individual replicates. Concentrations were less than 30 μg/kg in the corresponding reference tissues.

Platform Hilda

PCBs were not detected in either clam or worm tissue exposed to Hilda shell mound sediment. The only pesticides detected were DDT and related metabolites. . No pesticides were detected in worm tissues. The total pesticide level in Heidi clam tissue was 23.7 μg/kg, which is approximately 3 times lower than the reference level (82.9 μg/kg). Concentrations of chlorinated pesticides and PCBs in test tissues were not statistically different from those in reference tissues.

Concentrations of PAHs in Hilda clam tissue ranged from ND to 88.1 μg/kg for phenanthrene, and from ND to 348 μg/kg for naphthalene in worm tissue. Total PAH concentrations were 220 μg/kg and 569 μg/kg for test clam and worm tissues, respectively. The reference tissue concentrations for both clams and worms were 20 and 27 μg/kg, respectively. The average total PAH concentration in Hilda clam tissue was 11 times higher than the reference tissue level, and the average concentration in test worm tissue was 21 times higher than the reference tissue level. The total PAH levels in both clams and worms were significantly higher than reference tissue levels.

Average concentrations of methyl-substituted naphthalenes (1-methyl- and 2-methyl-) reached 217 μg/kg and 374 μg/kg, respectively, in test worm tissues and up to 12.7 μg/kg and 17.9 μg/kg, respectively, in clam tissues. Concentrations of 1-methylphenanthrene, 2,6-dimethylnaphthalene, and 2,3,5-trimethylnaphthalene were also present at concentrations exceeding 100 μg/kg in the test worm tissues and at

concentrations up to 65 μg/kg in the test clam tissues in individual replicates. Concentrations were less than 30 μg/kg in the corresponding reference tissues.

Platform Hope

PCBs were not detected in either clam or worm tissue exposed to Hope shell mound sediment. Two pesticides were detected: 1) DDT and metabolites and 2) chlordane. Chlordane was only detected in one clam tissue replicate at a very low level. No pesticides were detected in worm tissue. The total pesticide level in Hope clam tissue was 4.3 μg/kg, which is approximately 19 times lower than the reference level (82.9 μg/kg). Concentrations of chlorinated pesticides and PCBs in test tissues were not statistically different from those in reference tissues.

Concentrations of PAHs ranged from ND to 39.7 μg/kg for phenanthrene in Hope clam tissue, and from ND to 225 μg/kg for naphthalene in worm tissue. Total PAH concentrations were 121 μg/kg and 344 μg/kg for test clam and worm tissues, respectively. The reference tissue concentrations for both clams and worms were approximately 20 and 27 μg/kg, respectively. The average total PAH level in test clam tissue was 6 times higher than the reference tissue level, and the average concentration in test worm tissue was 12 times higher than the reference tissue level. The total PAH levels in both clams and worms were significantly higher than respective reference tissue levels.

Average concentrations of methyl-substituted naphthalenes (1-methyl- and 2-methyl-) reached 142 μg/kg and 155 μg/kg, respectively, in test worm tissues and up to 26 μg/kg and 50 μg/kg, respectively, in clam tissues. Concentrations of 1-methylphenanthrene, 2,6-dimethyl-naphthalene, and 2,3,5-trimethylnaphthalene were also present at concentrations exceeding 100 μg/kg in the test worm tissues and up to 65 μg/kg in the test clam tissues in individual replicates. Concentrations were less than 30 μg/kg in the corresponding reference tissues.

## 4.4 DATA QUALITY REVIEW

### 4.4.1 Bulk Sediment Analyses

Routine *Green Book* standard operating procedures were employed during all phases of this study. These procedures included appropriate sediment collection and handling procedures; analyzing samples within holding times; conducting duplicate, method blank, and laboratory control analyses at required frequencies; and using EPA-approved testing methods with state-of-the-art instrumentation.

Target detection limits (TDLs) for all chemical analyses were described in the project-specific SAP (AMEC 2001). Most of the detection limits were achieved for the bulk sediment analyses. Elevated detection limits are not unexpected in marine sediments and are commonly the results of matrix interferences such as high sulfides and salt content. The overall quality of the bulk sediment chemistry data is acceptable for

purposes of this characterization. A more detailed discussion of these issues follows. Laboratory quality control data are included in Appendix E.

Platforms Hazel and Heidi

*Data Quality Summary*: TDLs were achieved for the majority of the analyses performed. Detection limits were elevated for the TPH, TRPH, and PAH analyses due to the required sample dilution and matrix interference. Due to the elevated recoveries in the EPA Method 8270C surrogates, the reported values for the corresponding samples of phthalates and PAHs may be slightly elevated due to matrix interference effects. The reported values of the analytes antimony, 1,2-dichlorobenzene, and ethanol are slightly below the actual value due to a decrease in the matrix spike analysis recovery. The matrix spike duplicates did not bias the reported values of copper, lead, and selenium because the initial spike and the laboratory control spikes are all within the control limits (personal correspondence with Bob Stearns, Calscience). When a sample matrix contains substances (interferents) that interfere with the ability to identify and/or quantify target analyte(s) following standard procedures, matrix interferences are said to exist. Where matrix interferences are problematic, standard procedures must be modified to reduce their effects. Often, these (modified) procedures result in elevated reporting limits (RLs) because the RLs are derived from data resulting from following the standard procedures.

Marine sediments always contain matrix interferents that must be reduced. For trace metals, ICP is very susceptible to salt interference. To reduce the salt effect, sample dilution is required. However, with required dilution, ICP RLs become unacceptably high and, thus, ICP/MS is used. ICP/MS is also susceptible to salt interference but not to the extent of ICP. Therefore, even with sample dilution, ICP/MS RLs are lower. Marine sediments also usually contain undifferentiated hydrocarbons and, on a less frequent basis, sulfides. When hydrocarbon interference is present, sample dilution is required, which results in elevated RLs. The (electron capture) detectors used for pesticide/PCB determinations are very sensitive to sulfur. Therefore, when samples contain any form of sulfur, a sulfur cleanup procedure must be performed. Sulfur cleanups cause sample dilution. Hydrocarbon interference can also affect semivolatile hydrocarbon determinations (e.g., PAHs). When necessary, gel permeation cleanup (GPC) procedures are used to minimize the matrix interference effect posed to semivolatiles. GPC cleanups also result in sample dilution.

RLs only have meaning when the associated sample result is non detect (ND). Where sample dilution results in elevated RLs and where associated results are ND, it simply means that the target analyte(s) may be present at any concentration less than the RL. Thus, the higher the RLs for ND results, the higher the target analyte concentration may be, if present at all.

*Method Blank Analyses*: All blanks, run concurrent with the test sediment, were measured as “non detect” (ND) indicating that laboratory contamination was not a factor in the test results.

*Surrogate Recoveries*: The majority of the surrogate recoveries fell within the acceptable control limits except for the following:

| Method | Surrogate | Recovery Percent (%) | Control limits (%) | Data Qualifier |
|---|---|---|---|---|
| 8270C | p-Terphenyl-d14 | 179 | 18-137 | 2* |
| 8270C | Nitrobenzene-d5 | 131 | 23-120 | 2* |

*Data Qualifiers
2. Surrogate spike compound was out of control due to matrix interference. The associated method blank surrogate spike compound was in control and, therefore, the sample data were reported without further clarification.
3. Spike or Spike Duplicate compound was out of control due to matrix interference. The associated LCS and/or LCSD were in control and, therefore, the sample data were reported without further clarification.
4. The MS/MSD RPD was out of control matrix due to matrix interference. The associated LCS and/or LCSD were in control and, therefore, the sample data was reported without further clarification.

*Duplicate Analyses*: All duplicate analyses were within the control limit range.

*Matrix Spike Analyses*: The majority of the spike analyses were within the allowable control limits except for the following:

| Analyte | Matrix Spike (%) | Recovery Control Limits (%) | Data Qualifier |
|---|---|---|---|
| Antimony | 38 | 80-120 | 3* |
| 1,2-dichlorobenzene | 66 | 70-130 | 3* |
| Ethanol | 0 | 60-140 | |

*see qualifier list above

*Matrix Spike Duplicates*: The only duplicates that were not within allowable control limits include the following:

| Analyte | Matrix Duplicate Spike (%) | Recovery Control Limits (%) | Data Qualifier |
|---|---|---|---|
| Copper | 72 | 80-120 | 3* |
| Lead | 238 | 80-120 | 3,4* |
| Selenium | 76 | 80-120 | 3* |
| 1,2-dichlorobenzene | 68 | 70-130 | 3* |
| Ethanol | 0 | 60-140 | |

*see qualifier list above

*Laboratory Control Spikes/Spike Duplicates*: All spikes and spike duplicates fell within the allowable control limits.

Platforms Hilda and Hope

*Data Quality Summary*: TDLs were achieved for the majority of the analyses performed. Detection limits were elevated for the TPH, TRPH, and PAH analyses due to the required sample dilution and matrix interference. Due to the elevated recoveries in the EPA Method 8270C surrogates, the reported values for the corresponding samples of phthalates and PAHs may be slightly elevated due to matrix interference effects. The reported values of the analyte antimony will be negatively biased from the actual value due to a decrease in the matrix spike analysis recovery. The matrix spike duplicate did not bias the reported values of cobalt, lead, selenium, and methyl tertiary butyl ether

(MTBE) because the initial spike and the laboratory control spikes are all within the control limits.

*Method Blank Analyses*: All blanks, run concurrent with the test sediment, were measured as ND indicating that laboratory contamination was not a factor in the test results.

*Surrogate Recoveries*: The majority of the surrogate recoveries fell within the acceptable control limits except for the following:

| Method | Surrogate | Recovery Percent (%) | Control limits (%) | Data Qualifier |
|---|---|---|---|---|
| 8270C | p-Terphenyl-d14 | 168 | 18-137 | 2* |
| 8270C | p-Terphenyl-d14 | 158 | 18-137 | 2* |
| 8270C | p-Terphenyl-d14 | 177 | 18-137 | 2* |

*see qualifier list above

*Duplicate Analyses*: All duplicate analyses were within the control limit range.

*Matrix Spike Analyses*: The majority of the spike analyses were within the allowable control limits except for the following:

| Analyte | Matrix Spike (%) | Recovery Control Limits (%) | Data Qualifier |
|---|---|---|---|
| Antimony | 38 | 80-120 | 3* |

*see qualifier list above

*Matrix Spike Duplicates*: The only duplicates that were not within allowable control limits include the following:

| Analyte | Matrix Duplicate Spike (%) | Recovery Control Limits (%) | Data Qualifier |
|---|---|---|---|
| Cobalt | 72 | 80-120 | 3* |
| Lead | 238 | 80-120 | 3,4* |
| Selenium | 76 | 80-120 | 3* |
| MTBE | 71 | 80-120 | 3* |

*see qualifier list above
LCS - laboratory control spike
LCSD - laboratory control spike duplicate
MS - matrix spike
MSD - matrix spike duplicate
RPD - relative percent difference

*Laboratory Control Spikes/Spike Duplicates*: All spikes and spike duplicates fell within the allowable control limits.

### 4.4.2 Toxicity Tests

All biological testing was performed following the guidance provided by the *Green Book* (USACE/EPA 1991) and associated protocols. All bioassay tests met the data quality objectives (e.g., control survival, water quality parameters) of the EPA-approved procedures with the exception of the 10-day solid phase amphipod test. The first amphipod test was deemed unacceptable due to control treatment survival of 86 percent, versus the required level of 90 percent. This result indicates that either the test organisms and/or test conditions were not optimal. Control survivorship in the second test (95 percent) was greater than the 90 percent requirement. The second amphipod test was deemed valid.

### 4.4.3 Bioaccumulation Tests

The majority of the target detection limits were achieved for the bioaccumulation tissue samples. Two out of three replicates in the Hope worm test were unusable due to 100 percent worm mortality. The Hope clam replicates were unaffected. Control survival was 87 percent for the clams and 94 percent for the worms at the end of the 28-day test period. These levels exceed the 70 percent criteria required by the *Green Book*.

# 5.0 DISCUSSION

## SEDIMENT CHEMISTRY

The bulk sediment chemical contamination at the Chevron 4H Shell Mounds was generally widespread with particular contaminants detected at elevated levels of concern. Chemical analyses were performed on each stratum (top, middle and bottom) of each shell mound, as well as a site composite of all the strata, which was also used to conduct the bioassay and bioaccumulation analyses. The logic for conducting sediment analyses in this manner was to assist in the identification of core segments containing elevated levels of chemicals that may have been responsible for any toxicity observed in the bioassay analyses. If a sediment segment(s) can be identified as the likely cause of the observed toxicity, it can be isolated and disposed of by some alternative means (other than ocean disposal). The goal of testing in this fashion is to maximize the amount of sediment that can be placed at LA-2, and to minimize the volume of sediment that has to undergo an alternative disposal method.

The measured sediment values are compared to ERL and ERM values. These are criteria developed by the National Oceanic and Atmospheric Administration (NOAA) as informal guidelines used for interpreting chemical data. Values below the ERL represent concentrations below which adverse effects rarely occur. The ERM values represent concentrations above which effects frequently occur. The mean ERM quotient (ERMq) is also used to determine sediment toxicity when chemical mixtures are being assessed. The ERMq compares the analytes measured value to the ERM and gives a value of relative excess above or below the ERM. ERMq values below 0.51 are of low and low-medium concern and values above 0.51 are of medium-high and

high concern. The degrees of concern are based upon a combination of toxicity classification schemes used in bioassay data for 1,068 samples. The tests conducted were amphipod survival, sea urchin, and Microtox tests (Long et al., 1991). Table 14 provides the ERMq comparison for metals and organics found in the sediment strata.

The AET is also used for sediment quality comparisons. The AET is the highest concentration at which statistically significant differences in observed adverse biological effects from reference conditions do not occur, provided that the concentration also is associated with observance of a statistically significant difference in adverse biological effects.

## TOXICITY TESTS

For a sediment sample to be in compliance with a water column limiting permissible concentration (LPC), the concentration of the suspended-particulate phase in the water column at the disposal site must be below 1/100 of the calculated $LC_{50}$ for the test following a 4-hour initial mixing period. Water column LPC calculations are done using the short-term fate (STFATE) module of the Automated Dredging and Disposal Alternatives Modeling System (ADDAMS). The $LC_{50}$ or $EC_{50}$ for a suspended-particulate test is input into the model, along with other parameters (e.g., site conditions, grain size), to determine LPC compliance. Since all $LC_{50}$ and $EC_{50}$ values were >100 percent, no modeling is necessary to determine that the sediment does meet the water column LPC.

The solid phase survival results are compared statistically against reference survival to determine if there is a significant reduction in survival. The reduction must be greater than 10 percent below the reference level for the mysid shrimp test and 20 percent below the reference level for the amphipod test. All the amphipod tests and three of the mysid shrimp tests were found to be significantly toxic based upon these assessment criteria.

## METAL BIOACCUMULATION

Barium is not part of the standard list of analytes used to assess the suitability of sediments for ocean disposal because typically it is not considered a major contaminant of concern for dredging projects. However, because barium was used at the platforms during drilling and routinely disposed in the ocean, it occurs at considerably elevated concentrations in the shell mound sediments (ranging from 3,870 to 5,490 mg/kg) compared to the reference sediment level of 76 mg/kg. The elevated barium levels in the test sediments resulted in highly significant bioaccumulation in both worm and clam tissue, with average concentrations in test tissues from 16 to 61 times higher than the concentrations in reference tissue. Comparable bioaccumulation of one of the traditional heavy metal contaminants (e.g., copper, lead, or mercury) would have precluded ocean disposal at LA-2, but barium bioaccumulation at these levels is of lesser toxicological importance.

**Table 14. ERM Quotient Comparison for Each Sediment Stratum**

| Analyte | Units (dry wt.) | Hazel | | | | Heidi | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Top | Middle | Bottom | Comp. | Top | Middle | Bottom | Comp. |
| Arsenic | mg/kg | 0.07 | 0.13 | 0.08 | 0.10 | 0.04 | 0.08 | 0.04 | 0.03 |
| Cadmium | mg/kg | 0.00 | 0.19 | 0.00 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 |
| Chromium (Total) | mg/kg | 0.18 | 0.27 | 0.12 | 0.22 | 0.13 | 0.13 | 0.32 | 0.10 |
| Copper | mg/kg | 0.07 | 0.12 | 0.03 | 0.12 | 0.10 | 0.10 | 0.04 | 0.04 |
| Lead | mg/kg | 0.14 | 0.50 | 0.07 | 0.44 | 0.08 | 0.07 | 0.05 | 0.06 |
| Nickel | mg/kg | **0.63** | **1.05** | **0.70** | **1.23** | 0.37 | 0.33 | 0.64 | 0.32 |
| Silver | mg/kg | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Zinc | mg/kg | **1.49** | **0.84** | 0.38 | **0.92** | **1.03** | **1.21** | 0.21 | **0.91** |
| Mercury | mg/kg | 0.07 | 0.12 | 0.00 | 0.10 | 0.05 | 0.00 | 0.07 | 0.07 |
| Aroclor-1254 | µg/kg | **0.89** | **0.83** | 0 | **0.72** | 0 | 0 | 0 | 0 |
| **Analyte** | **Units (dry wt.)** | **Hilda** | | | | **Hope** | | | |
| | | **Top** | **Middle** | **Bottom** | **Comp.** | **Top** | **Middle** | **Bottom** | **Comp.** |
| Arsenic | mg/kg | 0.06 | 0.07 | 0.06 | 0.07 | 0.05 | 0.07 | 0.05 | 0.03 |
| Cadmium | mg/kg | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Chromium (Total) | mg/kg | 0.12 | 0.28 | 0.08 | 0.15 | 0.05 | 0.05 | 0.36 | 0.10 |
| Copper | mg/kg | 0.08 | 0.06 | 0.04 | 0.05 | 0.03 | 0.03 | 0.11 | 0.05 |
| Lead | mg/kg | 0.14 | 0.35 | 0.03 | 0.07 | 0.07 | 0.36 | 0.06 | 0.13 |
| Nickel | mg/kg | 0.37 | **0.75** | **0.51** | **0.59** | 0.15 | 0.30 | **0.57** | 0.30 |
| Silver | mg/kg | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Zinc | mg/kg | **0.92** | **0.70** | 0.21 | **1.14** | **1.02** | **1.40** | 0.33 | 1.20 |
| Mercury | mg/kg | 0.08 | 0.00 | 0.00 | 0.05 | 0.14 | 0.00 | 0.00 | 0.12 |
| Aroclor-1254 | µg/kg | **1.22** | **1** | 0 | 1.17 | 8.89 | 0.31 | 0 | 2.22 |

Comp. – Composite of 3 strata
dry wt. – dry weight
**bold** – medium - high concern
box – high concern
ERMq – measured concentration/ERM
mg/kg – milligrams per kilograms
µg/kg – micrograms per kilogram

ERMq toxicity classification
<0.1: low concern
0.11-0.5: low-medium concern
0.51-1.5: medium-high concern
>1.5: high concern

It is possible that some of the barium measured in the test tissue samples was associated with residual sediment that remained in the digestive tract of the test organisms following the 24-hour depuration period. To evaluate whether this occurred, a comparison to one of the other metals (zinc) that was elevated in the test sediment was made. For example, the Platform Hope shell mound had a sediment zinc concentration (493 mg/kg) that was approximately 12 times higher than the zinc concentration (41.6 mg/kg) in the reference sediment. The Hope shell mound sediment barium concentration (5,490 mg/kg) was 72 times higher than the reference sediment level (76.0 mg/kg).

By comparison, the average zinc concentrations in clam and worm tissues exposed to Hope shell mound sediments were 78.7 and 59.0 mg/kg, respectively. These levels are only 0.92 times and 0.60 times the reference tissue zinc levels (i.e., the test tissue level of zinc was less than the reference tissue level). If sediment had remained in the gut following the depuration period, the level of zinc in the test tissues would be expected to be much higher, reflecting the elevated zinc concentrations in the test sediments. Consequently, the results indicate that the elevated barium concentrations in the test clam and worm tissues were due to bioaccumulation rather than residual sediments in the guts of test organisms.

## ORGANICS BIOACCUMULATION

Test results showed that PCB and pesticide bioaccumulation was minor or non-detectable in both clam and worm tissue for all shell mound sediments. The Food and Drug Administration (FDA) Action Level for Poisonous or Deleterious Substances in Fish and Shellfish for DDT is 5 mg/kg (wet weight). The highest DDT concentration observed in this study was 0.09 mg/kg (dry weight) for Hazel clam tissue, which is over 50 time lower than the FDA Action Level. The LPC for bioaccumulation is met for both PCBs and pesticides.

Total PAH levels in clam tissue ranged from 6 (Hope) to 11 (Hilda) times greater than the average reference tissue concentration. For worms, the total PAH levels ranged from approximately 12 (Hope) to 27 (Hazel) times greater than the reference worm tissue level. Aside from concentrations of alkyl-substituted naphthalenes and phenanthrene, unsubstituted phenanthrene had the highest concentration in all clam tissue samples, while naphthalene had the highest degree of bioaccumulation in worm tissue. The presence of relatively high concentrations of the alkyl-substituted naphthalenes and phenanthrene in tissues of test organisms reflects the presence of unweathered petroleum hydrocarbons in the shell mound sediments.

There are no FDA Actions Levels for any PAHs. Since PAH bioaccumulation was statistically significant, the determination as to whether the tissue levels observed in this study are an ecological concern (i.e., met LPC bioaccumulation compliance criteria for ocean disposal) is based on the following factors as outlined in the *Green Book*.

- Number of species in which bioaccumulation was observed:

  Bioaccumulation was observed in both species tested.

- Number of contaminants that had statistically significant bioaccumulation:

  For the organic analyses, only PAHs were significantly elevated in tissues of test organisms.

- Number of contaminants statistically greater in test tissue versus reference tissue:

  Total PAH test tissue bioaccumulation was significantly greater in both clams and worms for all four sediments tested compared to the corresponding reference tissue level.

- Magnitude of bioaccumulation versus reference tissue:

  Total PAH bioaccumulation in test clam tissue was 6 to 11 times that of the average reference tissue level. PAH bioaccumulation in worm tissue was 12 to 27 times that of the average reference tissue concentration. Bioaccumulation factors for individual alkyl-substituted naphthalenes and phenanthrenes were relatively larger.

- Toxicological importance of bioaccumulated contaminants:

  PAHs are widespread environmental contaminants and are considered significant contaminants of concern when assessing dredged material disposal options. Alkyl-substituted naphthalenes and phenanthrenes can have relatively high acute toxicity to marine organisms, which is consistent with the results from the amphipod solid-phase bioassay tests. Benzo(a)pyrene, which is a known carcinogen, was not detected in either clam or worm tissue for all four sites.

- Phylogenetic diversity of the species tested:

  The two species tested represent particle feeders (clams) and deposit feeders (worms).

- Propensity for the bioaccumulated chemicals to biomagnify:

  The biomagnification potential for PAHs is minor, and is more of a concern on clams than worms because worms have the ability to metabolize PAHs. Clams, conversely, do not metabolize PAHs and can pass them through the food chain. PAH bioaccumulation in clam tissue in this study was 2 to 3 times lower than worm tissue levels.

- Magnitude of toxicity observed in solid and suspended-particulate phase tests:

  No toxicity was observed in any of the suspended-particulate phase tests. This may be due in part to the relatively high volatility of alkyl-substituted naphthalenes and phenanthrenes and other volatile aromatic compounds that were present in the shell mound sediments. Statistically significant

bioaccumulation was observed in all four amphipod solid phase tests, and three (Hazel, Heidi, and Hilda) solid phase mysid shrimp tests.

- Concentration levels of comparable species at the LA-2 disposal site:

  Since reference sediment is used in lieu of disposal site sediment for bioaccumulation exposures, this question is not addressed by this study.

The following section provides a discussion of the test results for the reference sediment and each individual platform:

## 5.1 REFERENCE SEDIMENT

As expected, the reference sediment was relatively void of analytes and most of the detectable analytes were below ERL, ERM, and AET values. Ten of 17 metals and/or general analytes were detected and only barium exceeded the AET value. No PAHs, volatile organics, TPH, PCBs, phenols, or organotins were detected. The pesticide 4,4'-DDE was measured above ERL values and TRPH were detected but did not exceed any of the ERL, ERM, or AET guidance values.

## 5.2 PLATFORM HAZEL

Overall, there was sediment contamination throughout the shell mound. Several metals and the PCB Aroclor-1254 were significantly elevated above ERM and AET guidance values. The majority of the organic contamination was contained in the middle stratum and at levels exceeding guidance criteria and reference levels. Toxicity was detected in the amphipod and mysid solid phase tests.

### 5.2.1 Sediment Chemistry

The results indicate evidence of chemical contamination in all of the Hazel shell mound strata as well as the composite sample. The metals zinc and nickel and the PCB Aroclor-1254 were found at elevated levels determined to be of medium-high concern based upon their ERMq values. Barium, chromium, selenium, zinc, and Aroclor-1254 also exceeded their AET values, an indication of increased statistical probability for causing adverse biological effects. Petroleum hydrocarbons were found throughout the shell mound strata with the majority of contamination located in the middle stratum. The PAH contamination was limited to the top and middle strata with only naphthalene elevated above its ERL value. The middle and bottom strata also contained volatile organics of which p/m-xylene exceeded its SQB. Phenols, pesticides, and organotins were not detected in any stratum but phthalates were detected in the top stratum at low levels relative to the reference sediment.

### 5.2.2 Bioassay

The bioassay data indicated statistically significant toxicity in the amphipod and mysid solid phase tests that is consistent with the presence of contaminants detected in the chemical analyses. The bivalve elutriate test did exhibit toxicity but the $EC_{50}$ was greater than 100 percent. Measures described earlier were taken during testing to decrease the effects of elevated sulfide and ammonia levels.

### 5.2.3 Bioaccumulation

Only the heavy metal barium and total PAHs were statistically elevated in test issue. The levels observed in test tissue is consistent with the concentrations observed in the test sediment. Methylnaphthalenes were also detected in elevated levels in both clam and worm tissue compared to the reference tissue levels.

## 5.3 PLATFORM HEIDI

Overall, there was sediment contamination throughout the shell mound. Barium and zinc were the most elevated of the metal contaminants. The majority of the organic contaminants were located in the middle stratum and were elevated in comparison to the reference sediment. The pesticide 4,4-DDE was located in the top stratum but below reference levels. Phenols and organotins were not detected. Toxicity was detected in the amphipod and mysid solid phase tests.

### 5.3.1 Sediment Chemistry

Metal contaminants were detected throughout the Heidi shell mound sediment. Barium and zinc were the two most prevalent metals and both exceeded their ERM and AET values in the top and middle strata. The bottom stratum and composite sample also contained elevated levels of barium relative to the AET values. Other metals in the bottom stratum did not exceed ERL or AET values but were elevated when compared to the reference sediment value. The majority of the organic contaminants were found in the middle stratum. Petroleum hydrocarbons, PAHs, and certain volatile organics were elevated in the sediment relative to the reference sediment or ERL values. The pesticide 4,4-DDE, the only pesticide detected in the shell mound samples, was identified in the top stratum but at levels below the reference sediment. Phenols and organotins were not detected in any strata and phthalates were detected only in the top stratum and at elevated levels relative to the reference sediment. Ammonia and sulfides were detected in all of the strata at levels exceeding the reference sediment values.

### 5.3.2 Bioassay

The bioassay toxicity results indicated significant amphipod and mysid toxicity in the solid phase tests that would be consistent with the elevated levels of contaminants

throughout the sediment. No toxicity was seen in the suspended-phase survival and development tests. Measures described earlier were taken during testing to decrease the effects of elevated sulfide and ammonia levels.

### 5.3.3 Bioaccumulation

Only the heavy metal barium and total PAHs were statistically elevated in test issue. The levels observed in test tissue is consistent with the concentrations observed in the test sediment. Methylnaphthalenes were also detected in elevated levels in both clam and worm tissue compared to the reference tissue levels.

## 5.4 PLATFORM HILDA

Overall, there was sediment contamination throughout the shell mound. Barium and zinc were the most elevated of the metal contaminants. The majority of the organic contaminants were located in the middle stratum and were elevated in comparison to the reference sediment. PCBs, phthalates and organotins were detected at elevated levels as well in the top stratum. Toxicity was seen in the amphipod and mysid solid phase tests.

### 5.4.1 Sediment Chemistry

Organic and metal contaminants were detected throughout Platform Hilda but were dominant in the middle stratum. Barium and zinc, in particular, were the metals of most concern due to their elevated levels above ERM and AET values. The zinc ERMq measured in the medium-high concern range. Other metals were detected at levels exceeding ERL values and elevated in comparison to the reference sediment levels. Although organics were found in all strata, elevated levels of TPH, TRPH, volatile organics, and PAHs dominated the middle stratum. The PAHs were detected at values exceeding their ERL values. Phenols and pesticides were not detected in any samples but phthalates and organotins were found in the top stratum at elevated levels relative to the reference sediment. The PCB Aroclor-1254 exceeded its AET and ERM values in the top and middle strata and the composite sample. Ammonia and sulfides were detected in all of the strata at levels exceeding the reference sediment values. The total sulfides were all elevated above reference sediment values and were dominant in the top stratum.

### 5.4.2 Bioassay

The bioassay results show statistically relevant toxicity in the amphipod and mysid solid phase tests consistent with the elevated levels of contaminants in the sediments. No significant suspended-phase toxicity was identified. Measures described earlier were taken during testing to decrease the effects of elevated sulfide and ammonia levels.

### 5.4.3 Bioaccumulation

Only the heavy metal barium and total PAHs were statistically elevated in test issue. The levels observed in test tissue is consistent with the concentrations observed in the test sediment. Methylnaphthalenes were also detected in elevated levels in both clam and worm tissue compared to the reference tissue levels.

## 5.5 PLATFORM HOPE

Overall, there was sediment contamination throughout the shell mound. Barium and zinc were the most elevated of the metal contaminants and both exceeded their ERM and AET values. The majority of the organic contaminants were located in the middle stratum and were elevated in comparison to the reference sediment. The PCB Aroclor-1254 was detected in extremely high concentrations in the top stratum and composite sample. All other organic contaminants were detected at levels above the reference sediment levels except for pesticides that were not found in the sediment at all. The amphipod solid phase toxicity test was the only test to result in positive toxicity.

### 5.5.1 Sediment Chemistry

Contaminants were detected throughout the sediment but were dominant in the middle stratum. Zinc and barium proved to be the most elevated of the metal contaminants. Zinc exceeded its ERM and AET values in the top and middle strata and composite sample while barium exceeded its ERM and AET values in all strata and the composite sample. Other metals detected in the bottom stratum did not exceed the ERL or AET values but were elevated compared to the reference sediment. Petroleum hydrocarbons, PAHs, and volatile organics measured the highest in the middle stratum. The PCB Aroclor-1254 was significantly elevated in the top stratum and composite sample with ERMq ratings of 8.9 and 2.2, respectively, the highest ratings of all contaminants and classified as concentrations of high concern. Phenols and phthalates were both detected in the middle stratum at elevated levels relative to reference sediments. Organotins were also detected above the reference levels in the top and middle strata and composite sample. Pesticides were not detected in the Hope shell mound samples. Ammonias and sulfides were detected in all of the strata at levels exceeding the reference sediment values. The total sulfides were all elevated above reference sediment values and were dominant in the top stratum.

### 5.5.2 Bioassay

The bioassay results contain toxicity in the amphipod solid phase test but not the mysid solid phase or suspended-particulate phase tests. The toxicity reflects the elevated amounts of contaminants seen in the sediment analyses. Measures described earlier were taken during testing to decrease the effects of elevated sulfide and ammonia levels.

### 5.5.3 Bioaccumulation

Only the heavy metal barium and total PAHs were statistically elevated in test issue. The levels observed in test tissue is consistent with the concentrations observed in the test sediment. Methylnaphthalenes were also detected in elevated levels in both clam and worm tissue compared to the reference tissue levels.

## 5.6 GRAIN SIZE EFFECTS

The overall grain size was primarily silt and sand. Only the amphipod test could be impacted by grain size characteristics. The recommended grain size for *Ampelisca* is >10 percent silt/clay (EPA 1994). The sediments tested in this study fall within the accepted grain size range for the amphipod used.

# 6.0 CONCLUSIONS

This study employed standard USACE and EPA protocols to assess the suitability for disposal of sediment from the 4H Shell Mound site at the designated Ocean Dredged Material Disposal Site referred to as LA-2. Conclusions of the *Green Book* Tier III study are:

- Sediment was dominated by silt and sand fractions.
- Shell mound sediment was moderately contaminated with some heavy metals (primarily barium and zinc), petroleum hydrocarbons, PAHs, PCBs, and VOCs.
- No statistically significant suspended-particulate phase toxicity was observed.
- Statistically significant toxicity was observed in all four solid phase amphipod exposures and three out of four (Hazel, Heidi, and Hilda) mysid shrimp tests.
- Statistically significant levels of barium and PAHs were detected in clam and worm tissue compared to reference tissue levels.

Section 103 of MPRSA Public Law 92-532 (the Ocean Dumping Law) requires that all dredged material proposed for open water disposal meet certain criteria. Environmental evaluations of the proposed dredged material are done in accordance with the applicable criteria published in Title 40, Code of Federal Regulations, Part 220-228. Dredged material is evaluated to determine its compliance with LPCs as defined by the ocean dumping regulations. Based on these evaluations, the 4H Shell Mound Sediment can be classified as follows:

- meets the LPC for water column effects;
- does not meet the LPC for benthic effects;
- does not meet the LPC for bioaccumulation.

Based on these results, LA-2 placement of the 4H Shell Mound sediment is not an acceptable disposal alternative.

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